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Improvements in Western Union's First Microwave Telegraph System

The first microwave system for commercial telecommunications was placed in service by Western Union in 1947 with radio equipment of RCA design adapted to the Telegraph Company's requirements. This first system has been described in the REVIEW in some detail. Recent changes and improvements in the radio apparatus have been aimed at broadened bandwidths throughout to assure ample margin for a 100-percent increase in beam circuit capacity. The modulator, 1-mc subcarrier amplifiers, the intermediate-frequency amplifiers, and even the demodulator, were either modified, broadened, or replaced. In addition, more carrier equipment was required, of course, to divide the resulting radio baseband into 32 voicebands.

As described in another article in this issue of the REVIEW, the carrier equipment at each terminal also was modified to double its accommodation range to 32 three-kilocycle bands.

Western Union's first microwave telegraph system, designed to meet the rigorous requirements of common carrier operations and constructed by RCA, was installed and put into use in 1947.[1] At the time, it represented the most technically

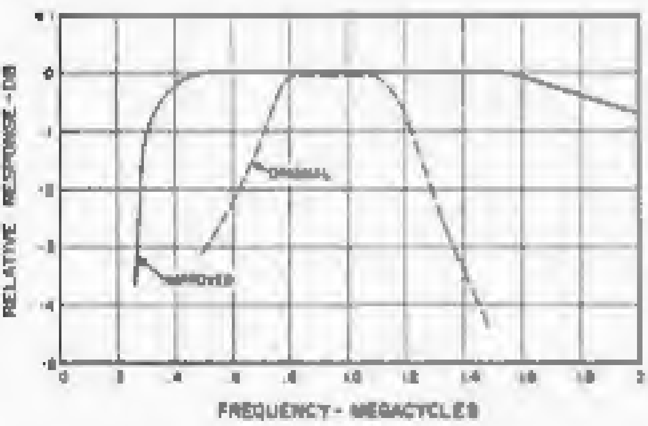

Figure 1. Subcarrier circuit frequency response

advanced equipment available and was a key part in the Telegraph Company's postwar modernization program. Operating experience soon revealed that the system could handle 16 voicebands reliably, rather than the hoped-for 32. Subsequent advances in the state of the art applied by Western Union engineers have been utilized in the improvement program completed in November 1955, and described herein.

One of the factors limiting the traffic load capacity to 16 voicebands was the narrow bandwidth of the 1-mc subcarrier stages of the equipment. Figure 1 shows the subcarrier circuit frequency response at one relay station and Figure 2 shows the frequency response of the original subcarrier modulator and demodulator. With the initial intended deviation of plus or minus 400 kc on peaks of the 1-mc subcarrier, tests indicated that considerable distortion was introduced by the cascading of several repeaters which reduced the already narrow bandwidth. Such distortion results in intermodulation crosstalk between voicebands. Therefore, the deviation of the subcarrier had to be reduced with a consequent decrease in FM improvement.

As shown in Figure 2, the back-to-back frequency response of the old modulator and demodulator was adequate for the 72-kc response required for 16-voiceband loading but fell short of 150 kc required

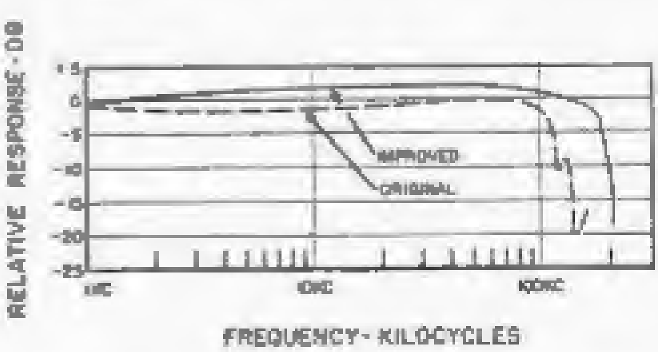

Figure 2. Modulator and demodulator frequency

for handling 32 voicebands. A major portion of this falloff was due to the modulator, with a lesser amount caused by the demodulator. The demodulator was critical with respect to tuning, required that the subcarrier frequency be maintained very close to 1.0 mc and caused objectionable distortion with increased voiceband loading.

In addition to the restricted passband, the original 1-mc circuits were incapable of supplying sufficient 1-mc voltage to deviate the 4000-mc carrier plus or minus 2 mc as its original design intended. Here again the decrease in FM improvement resulted in a further reduced signal-to-noise ratio (S/N).

Transmission of an FM signal deviated plus or minus 2 mc with low distortion requires an intermediate frequency (IF) amplifier passband in the order of 8 to 9 mc.[3] The nominal 4-mc bandwidth of the old equipment limited the actual system deviation to less than plus or minus 1 mc, with a consequent loss of FM improvement. Evidently the shape of the old IF passband as shown in Figure 3 could also bear improvement.

Solving the Problems

To correct the subcarrier level and bandwidth problems, two new 1-mc amplifiers were designed. One immediately follows the intermediate-frequency amplifier. It amplifies and combines the 1-mc demodulated output from main and diversity IF amplifiers, and drives a low-impedance coaxial cable leading to the transmitter head-end unit. Located in the transmitter head-end unit is a second 1-mc amplifier with sufficient gain and output to deviate the 2K56 Klystron plus or minus 2 mc. (See Figures 4 and 5.)

The combined response of these new 1-mc amplifiers is shown in Figure 1. Preliminary tests were made in the laboratory on ten tandem-connected amplifiers each comprising all of the subcarrier stages used at a repeater. S/N tests using 32-voiceband WN-2 equipment were run. There was no deterioration in signal-to-noise ratio through the amplifiers compared to carrier back-to-back measurements.

The original modulator was modified to correct for the falloff mentioned previously. This required compensation to maintain the input impedance constant to 150 kc. Several peaking and loading networks were employed but, all in all, the changes required were minor. The old demodulators were replaced with Federal Telecommunications Laboratories 113-A subcarrier receivers. These have none of the disadvantages noted previously for the old demodulator, are relatively insensitive to input level variation over a wide range, and require no alignment.

Back-to-back frequency response of the modified modulator and the FTL subcarrier receiver is shown in Figure 2.

To complement the improvements made on the subcarrier generation and transmission circuits, new intermediate-frequency amplifiers were designed. The nominal center frequency was changed from 32 to 33 mc and the passband is flat within plus or minus 1 db over its 8-mc width with a half power bandwidth of approximately 10 mc as shown in Figure 3. At Cub Hill and Elk Neck microwave repeater stations, where Forestry Service transmitters of around 33 to 34 mc are

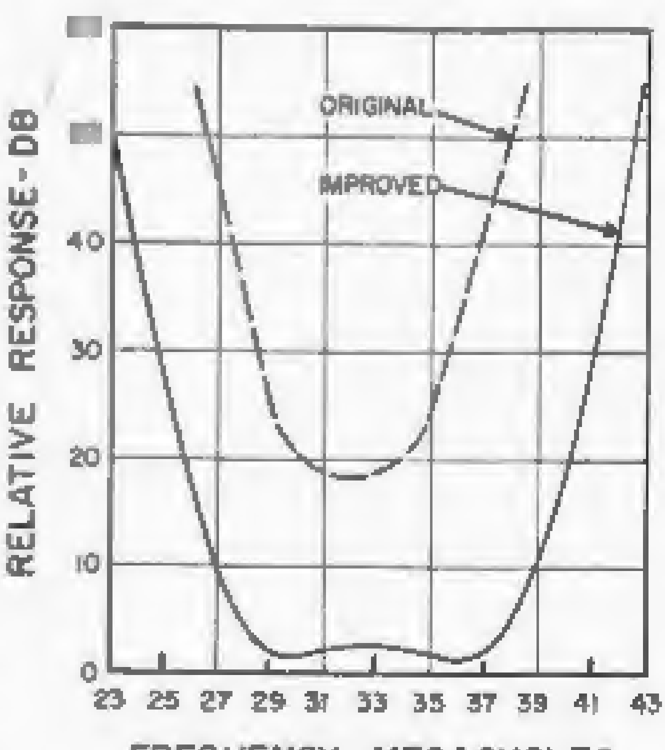

Figure 3. IF amplifier passband

located on Western Union relay towers, an IF of 41 mc was chosen to minimize the possibility of interference to Telegraph Company equipment.

Rack Changes

Addition of new equipment required certain rack changes. Originally there were two identical IF-amplifier panels each containing a 6-tube IF, a 2-stage 1-mc amplifier, and a service channel amplifier and gate control tube. In the changes, due to the need for more rack space to accommodate an extra power supply, two IF amplifiers (main and diversity) are mounted on a single panel (Figure 8) along with the 2-channel 1-mc amplifier and the service channel amplifier and gate control tubes. A new 160-volt power supply, mounted below the IF panel, furnishes plate power to the intermediate-frequency amplifiers. The new IF panel and 160-volt power supply occupy the same rack space previously occupied by the two old IF panels.

The FTL demodulator fills the space vacated by the old demodulator. A 300-volt power supply, needed to supply the higher current requirements of the subcarrier receiver, is mounted in rack space formerly occupied by a blank panel.

Units which have been changed the most, namely the 1-mc circuits, the IF amplifiers, and the demodulator will be described in detail.

1-MC Circuit Details

The block diagrams of Figures 4 and 5 locate the 1-mc stages with respect to the other units that make up the microwave relay system. Figure 6 further subdivides the 1-mc equipment for a clearer functional description.

The 100-millivolt, 1-mc subcarrier output of each IF is applied to its respective 1-mc amplifier through a bridged-T pad and a high-pass filter. The output of each 6AC7 broadband amplifier stage is applied to a grid of the 12AT7 dual triode connected as a cathode follower type of adder. The combined output of both main and diversity 1-mc signals, at a level of 0.2 volt, is obtained across a load resistance common to both halves of the 12AT7. The 75-ohm output impedance of this cathode follower matches the coaxial cable which joins the receiver 1-mc amplifier unit with the transmitter 1-mc amplifier at a repeater. The transmitter 1-mc amplifier, employing a 6AG7 beam power pentode, amplifies the 0.2-volt signal it receives to the level of 4 to 6 volts necessary to

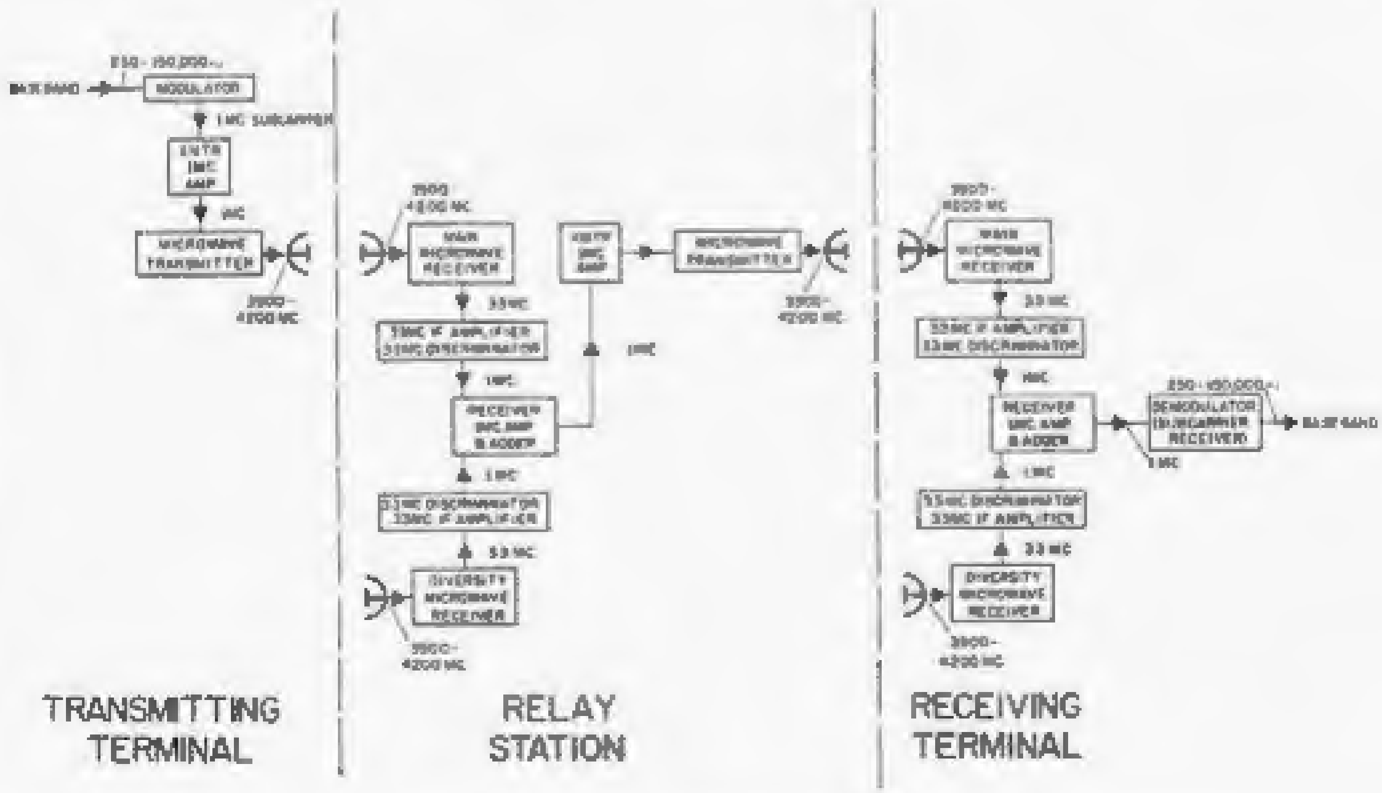

Figure 4. Double FM microwave relay system

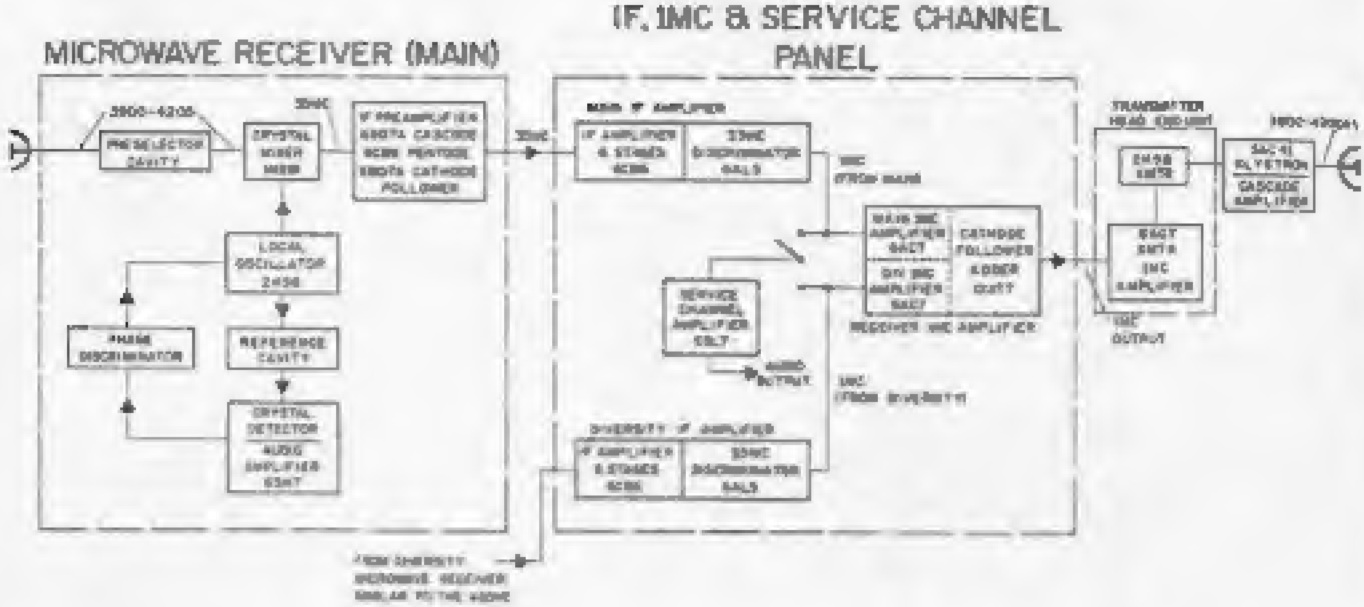

Figure 5. Receiver, IF amplifier, and subcarrier circuits

deviate the 2K56 Klystron ±2 mc. At terminals, the receiver 1-mc amplifier feeds the subcarrier receiver (demodulator).

The purpose of the high-pass filter noted in Figure 6 is to separate the service channel intelligence from the 1-mc subcarrier. The service channel signals are amplified for local use or for retransmission by means of a 6SL7 dual triode. A switch is provided to obtain the service channel from either main (regular) or diversity receiver, with the normal source being the "main." This switch provides continuity of the talk channel should either receiver be disabled for any reason by a maintainer. In the original system, the service channel was supplied by the main receiver alone, as part of a repeater fault-locating function. This function still has been preserved, with the switching feature adding flexibility.

IF Amplifier Changes

The IF circuit additions consist of two separate units, an IF preamplifier which mounts in the receiver head-end unit (see Figure 7), and the IF proper, two of which mount on a special mounting panel (Figure 8). The IF preamplifier consists of three tubes. The first, a 6BQ7A dual triode, is connected as a direct-coupled cascode low-noise amplifier. The IF noise figure is 4 db, which is 5.5 to 7.5 db better than the original equipment. The second tube, a 6CB6 pentode, is bandpass coupled to a second 6BQ7A, connected as a cathode follower. The output impedance of the cathode follower is 75 ohms. This value of impedance matches the RG-12/U armored coaxial cable which connects the receiver head-end unit to the IF amplifier, located some distance away. The impedance match obtained is superior to that of the old equipment. Previously, mismatch between cable and the IF amplifier caused severe reflections and standing waves to occur on the coaxial line. This new arrangement has been checked with 800 feet of coaxial cable without the appearance of any standing waves.

The IF amplifier proper consists of five bandpass-coupled 6CB6 pentode amplifiers. The stage gain is approximately 5.5 and the stage bandwidth 11 mc. Following the five amplifier stages is a biased diode limiter using two CK705/1N66 germanium crystal diodes. A final 6CB6 is used as the discriminator driver tube, and a 6AL5 duo-diode is the discriminator tube.

The IF units should require a minimum of realignment in the event of tube changes. This is brought about by the choice of interstage coupling networks which are pi-network equivalents of transitionally-coupled double-tuned circuits with equal Q's. The Q's are sufficiently low (and the circuit bandwidth sufficiently broad) so that the normal slight variations in interelectrode capacity

from tube to tube does not effect the response.

The IF amplifier is equipped with a gain control to permit adjustment of receiver sensitivity to the desired level as well as to compensate for the aging of tubes.

As is evident from Figure 3, in bandwidth and shape of response the new IF circuits are superior to the old.

Demodulator

As noted earlier, the old demodulators were replaced with FTL-113A subcarrier receivers, which are nothing more than FM demodulators designed to be used as part of a subcarrier system. As described elsewhere,[1] the advantage in using a subcarrier instead of direct modulation of an RF carrier is that frequency division multiplex signals can be transmitted over multihop microwave systems with relatively low crosstalk.

Use of a counter type discriminator results in a relatively simple receiver with no critical parts to align. This is a distinct advantage over the unit it replaces, with its complex circuitry and elaborate alignment procedure. The input frequency is 1.0 mc which can be frequency-modulated by frequencies between 0.250 kc and 150 kc. Satisfactory operation is obtained with input signals ranging in level from 0.05 to 1.0 volt. The output band of modulating frequencies is delivered to 135-ohm output terminals.

This receiver is shown in the block diagram of Figure 9 and consists of limiters, cathode followers, a counter discriminator, a low-pass filter, video amplifiers and output level metering.

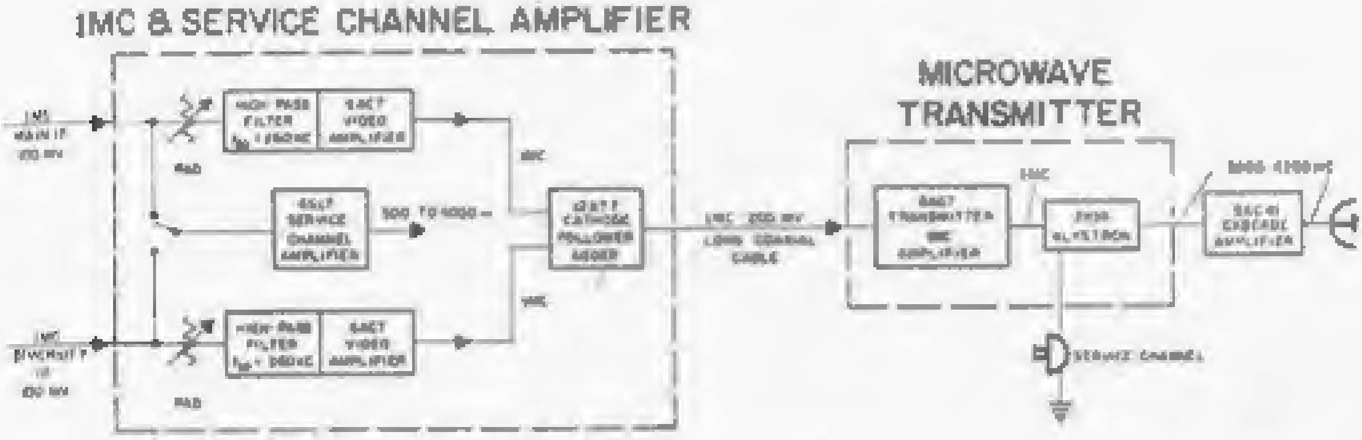

Figure 6. Repeater 1-mc circuit

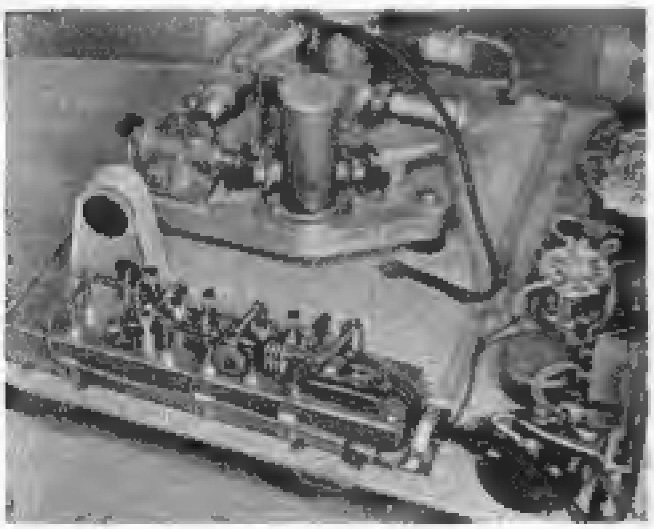

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Figure 7. IF preamplifier (foreground) and portion of receiver head-end unit

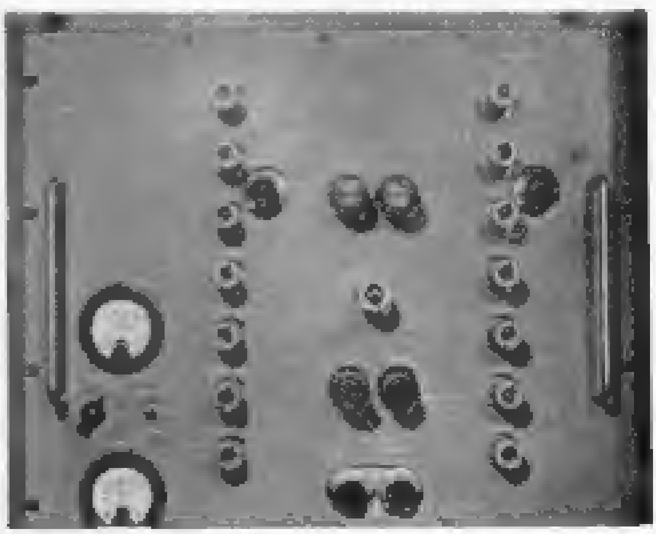

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Figure 8. IF and 1-mc amplifier panel

The function of each block is as follows: the limiters are required to convert the FM input signal to square waves of short rise time and equal output amplitudes, for each cycle over the deviated band. In this application, a rise time in the order of 0.05 microsecond and constant peak-to-peak amplitude over the band from 250 kc to 1.75 mc is provided. The limiters used are resistance, have a constant average amplitude for a constant frequency. The average output amplitude varies directly with the number of pulses per second, thus resulting in an essentially linear discriminator action. The counter output, developed across the load resistance, feeds a second cathode follower circuit V9, which is identical to that of V7. This

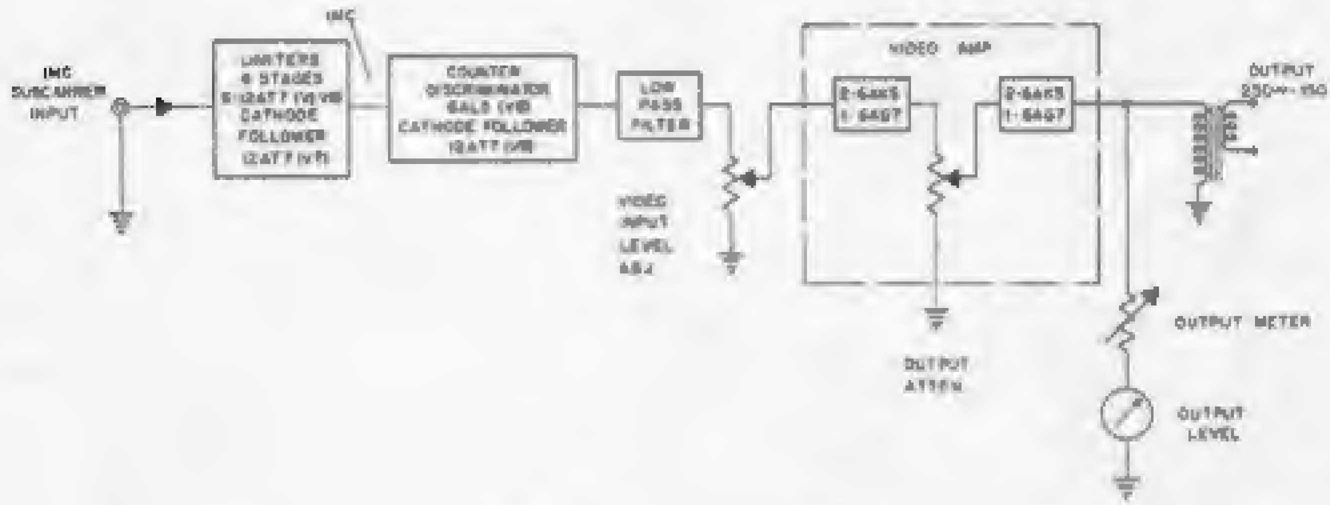

Figure 9. Subcarrier receiver

sometimes referred to as cathode-coupled clippers. Each limiter consists of a 12AT7 dual triode. The first section, a cathode follower, is coupled through the common cathode impedance to the second triode section. The first six stages referred to as limiters are identical. However, whether the tube limits or not depends on the level of the signal driving the stage. With inputs to each limiter of less than three volts RMS, the limiter stages become amplifiers with a gain of approximately three. For a subcarrier input of less than 0.3 volt RMS, the first two stages function as amplifiers and limiting begins to take place in the third stage.

The constant amplitude square wave generated by the limiters is supplied to the counter discriminator from the low-impedance cathode follower source V7. The voltage is approximately 15 volts peak to peak. A capacitor (30 μμf) is charged through the counter diode and discharged through a low resistance load (1K). The differentiated pulses, developed across this cathode follower drives the low-pass filter and isolates it from the filter. The low-pass filter serves to pass only the desired modulation frequency components in the 0.250-kc to 150-kc band. Since the highest modulation frequency is so close to the lowest subcarrier frequency, which may reach 250 kc on modulation peaks, a sharp cutoff filter is necessary. The filter employed is a 4-section pi designed to work into a 1000-ohm load and has a cutoff frequency of 200 kc.

The video amplifier noted in the block diagram consists of two 3-stage low-distortion feedback amplifiers. It can deliver an RMS output of +23 dbm to a 135-ohm load. At this output, the distortion is down at least 50 db. Frequency response of the video amplifier is flat within plus or minus 0.5 db from 250 cycles to 150 kc. The tube complement of each section is two 6AK5's and a 6AG7. To set the output level, a calibrated attenuator is provided. An output level meter serves as a continuous check on baseband output.

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Figure 10. Subcarrier receiver—front view

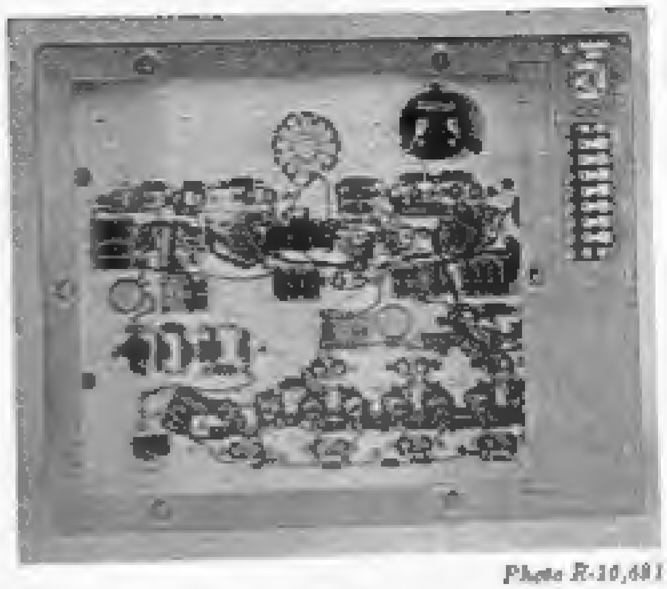

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Figure 11. Subcarrier receiver—rear view

Design Philosophy

Part of the philosophy in the design of new equipment for the New York—Washington—Pittsburgh triangle was to make the equipment as free as possible of the need for alignment. In the 1-mc stages any peaking circuits are factory set. Frequency response is essentially independent of tube replacement. This is also true of the IF amplifier, where the broadband interstage coupling networks make the over-all response almost independent of tube capacitance variation. The subcarrier receiver has no tuning adjustments at all, which eliminates the need for any alignment.

The results of this basic design concept have been most gratifying in providing greatly augmented circuit capacity.

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2. Electronic Circuits and Tubes, Cruft Laboratories, p. 657, McGraw-Hill.
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Mr. Grybowski's biography appeared in the April 1955 issue of Technical Review.

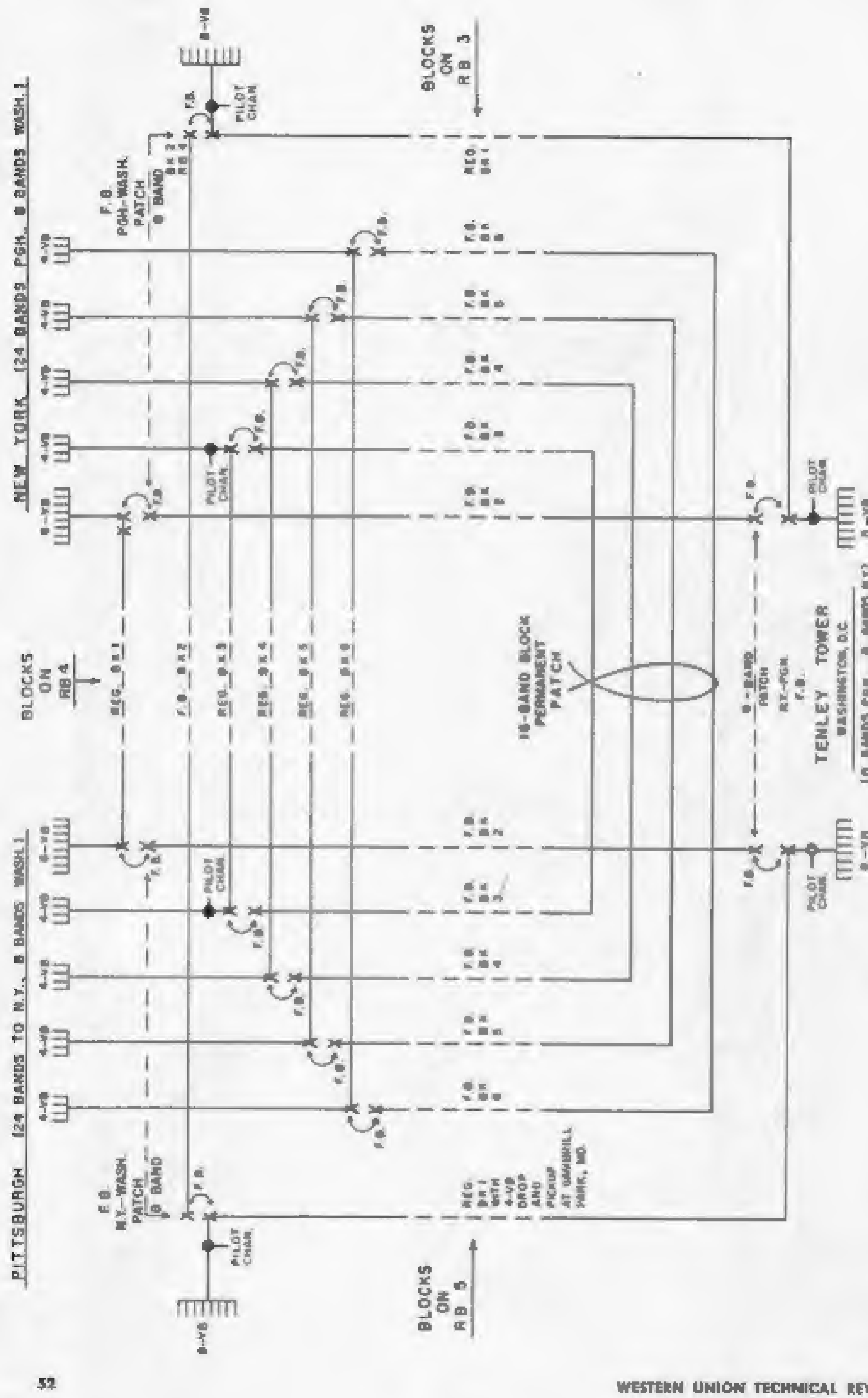

Figure 1. Triangle arrangement of bands and blocks in WN2.1 carrier system

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Radio Relay Carrier Improvements

Introduction of commercial microwave telecommunications service ten years ago under Western Union's leadership required concurrent installation of compatible channelizing apparatus at telegraph terminals. FM carrier equipment based on Western Union's original and now widely used designs was adapted to this requirement but inherent limitations in the microwave system prevented full-scale application of the carrier channelizing apparatus at that time.

Meanwhile, continued research has brought not only new microwave components but also improved FM carrier terminal apparatus which provided for 640 teleprinter circuits operating continuously on 640 different channel frequencies over 32 three-kilocycle bands with satisfactory signal-to-noise and crosstalk ratio.

EVER-INCREASING demand not only for more telegraph circuits but also for a more economical means of carrying Western Union traffic loads between major cities stimulates continuous development endeavor toward increasing the message capacity of Western Union's radio beam system and its associated voice-frequency channelizing equipment. It is normal practice by the company to operate 20 FM carrier teleprinter circuits in one 3-kc frequency band. In both telephone and telegraph parlance, the term "voice-frequency channel" or "band" (abbreviated vb for voiceband) implies that a frequency spectrum of approximately 3000 cycles is involved in the voice range. Among telegraph people, however, it rarely implies that any actual communication by voice is being considered. Generally, it simply denotes a unit spectrum in which a number of telegraph signaling channels can be carried.

Prior to December 1955, the systems which were installed 1945 to 1948 carried eight voicebands of traffic on the New York—Philadelphia radio beam and also on the New York—Pittsburgh—Washington radio triangle, with channelizing equipment operating in the baseband spectrum up to 32 kc. It was necessary to have fallback for these bands and the spectrum above 32 kc up to 72 kc was utilized for this purpose. Although the expectation in 1947-1948 contemplated a considerably higher limit, this is the maximum baseband width these beams could reliably carry and yet provide the proper minimum required signal-to-noise ratios. Effort was therefore directed toward increasing the baseband width to 150 kc, and this culminated in a system improvement program for which the installation and testing was completed in December 1955.

Only 16 Stable Bands Originally

The maximum baseband load of 16 bands was originally provided by WN1 carrier system channelizing equipment[1] installed in the latter part of 1948. Eight of these bands operated in the spectrum from 0.3 to 30.9 kc, and each of the three legs of the triangle carried eight separate bands. The fallback spectrum for any one block of these eight bands around the other two legs of this triangle was from 30.9 kc up to 71.7 kc. Actually only 7-1/2 bands were loaded with traffic, the unmodulated half of band A being used for an intercom servicing circuit going completely around the triangle.

Subsequent traffic requirements made it desirable to use 24 bands New York to Pittsburgh on Radio Beam No. 4 (RB4), 8 bands New York to Washington on RB3, and 8 bands Washington to Pittsburgh on RB5, with 4 bands dropped and picked up at Gambrill Park, Md., 44 miles west of Washington, D. C. In order that each leg of the triangle would have a fallback route for its normal traffic, the beams on

each route had to be capable of carrying 32 voicebands. For example, the normal 24 bands on RB4 are also carried on fallback over RB3 and RB5, and the 8 bands normally on RB3 or RB5 are also carried on fallback over RB4 and RB5, or RB3 and RB4. This, of course, requires that the carrier block and beam baseband equipment at each terminal be able to handle up to 32 voicebands. This article deals particularly with how the 32-voiceband capacity was established by *combining* the original WN1 carrier channelizing equipment with a modified version of the newer WN2 equipment.

In this issue of Technical Review an article on "Improvements in Western Union's First Microwave Telegraph System," by T. M. Grybowski, covers the changes in beam radio equipment to accomplish this doubling in beam capacity to 32 voicebands. Channelizing equipment for 32 bands in the baseband range between 3.9 and 147.3 kc had been previously developed.[1] However, full application of this WN2 equipment was not practicable until improvements in the radio relay equipment had been accomplished as described in Mr. Grybowski's article.

This solution to the channelizing equipment problem, reached in 1954, was justified by the time saved and proved economical since it permitted the WN1 to be retained, and made use of a considerable amount of unassigned WN2 equipment on hand. It would not be considered applicable today, however, for a completely new system. Both WN1 and WN2 carriers are more expensive to manufacture and require considerably more floor space than do other equipments now available.

Since it was necessary to retain the 8-band triangular arrangement of the WN1 and since the WN1 uses the lower half of the 150-kc spectrum, only that portion of the WN2 required for bands in the upper half was adapted to this application. As a result, 16 of the 24 bands on RB4 now operate in the baseband spectrum between 79.5 and 147.3 kc and the fallback for these 16 bands continuously uses the same spectrum over RB3 and RB5 through a permanent patch of these frequencies at Tenley Tower, Washington, D.C., as shown in Figure 1. The eight bands in Block 1 of each leg continue to operate in the spectrum between 0.3 and 30.9 kc and, as previously, use Block 2 for fallback in the spectrum from 41.1 to 71.7 kc. A new tuner was designed for the purpose of combining the system frequencies below 71.7 kc with those above 79.5 kc.

WN2.1 System is WN1 Plus WN2, Modified

The combined systems in this application (Figure 2) were called WN2.1 and the frequency division carrier terminals forming the triangular system divided the 150-kc baseband spectrum into two 8-band blocks and four 4-band blocks. One feature incorporated in this system which is most advantageous is the provision of a means for diversity transmission of both the 8-band and 4-band blocks over the fallback routes to eliminate the necessity for exact coordination in switching simultaneously the distant sending terminal and the receiving terminal. The same traffic signals over both routes appear at their respective 4-band block "receive" jacks which are located adjacent to the 4-band terminal "in" jacks thus providing the terminal attendant a choice of either route simply by inserting or removing a twin patching plug in the fallback receiving block. This procedure for switching has proved to cause no breaks in a telegraph channel regardless of how slow the patch is made.

Another feature of particular note about this switching from the regular to the fallback route (after all line-up and equalization adjustments are completed) is that the level of 20 channels on a db meter at practically all band receive jacks reads the same. In fact, the level remains so constant it is necessary to break the RB receive circuit in order to convince oneself that the switch has actually been made.

In regard to noise levels on a loaded beam, it was found that teleprinter ranges were very good even on the "J" channel at 375 cycles per second (ordinarily the poorest) in a band with the highest noise.

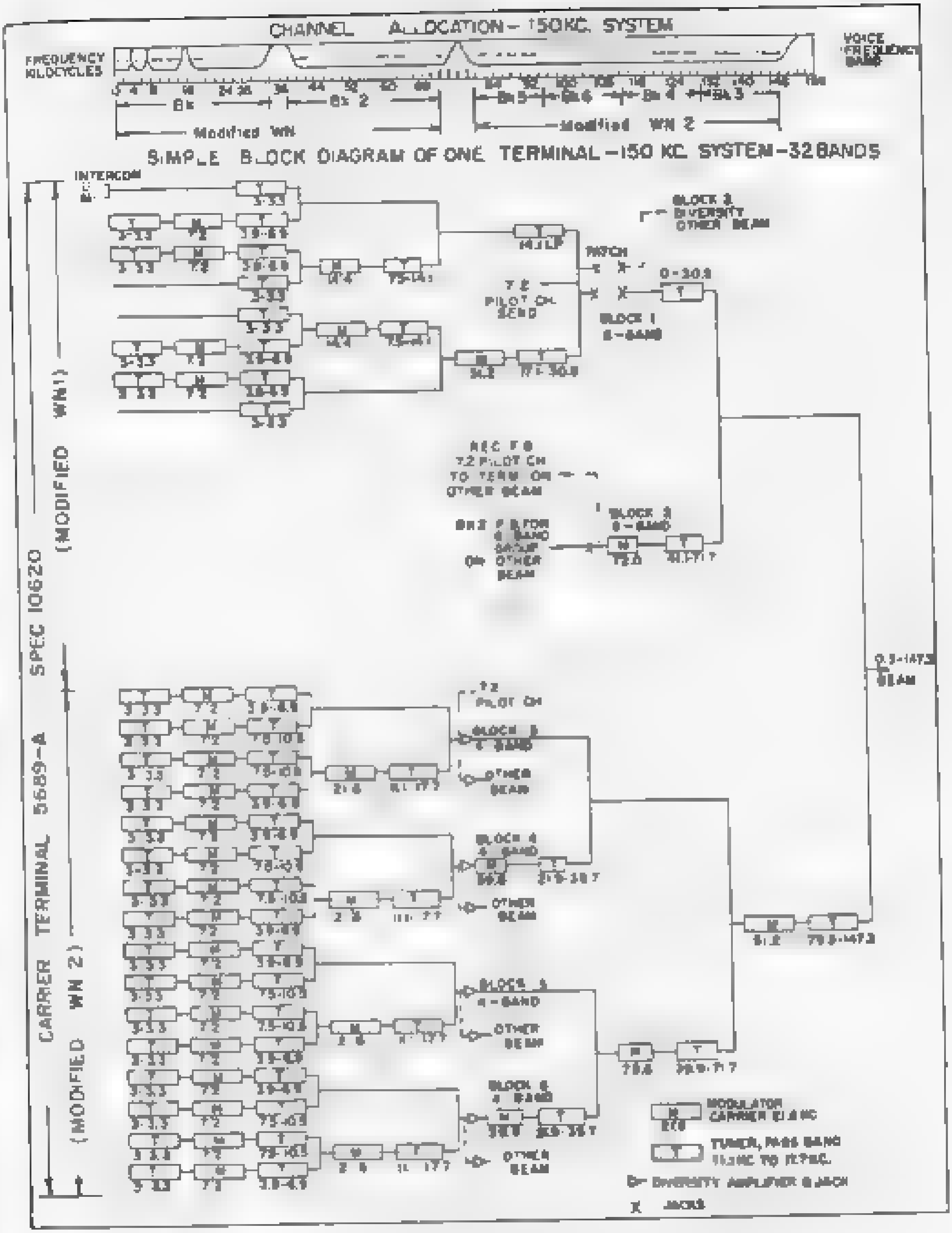

Figure 2. One terminal theory for carrier system WN2.1

The noise and crosstalk in the carrier equipment described above was 10 to 20 db lower than the noise plus crosstalk produced by the radio beam fully loaded

Two photographs (Figures 3 and 4) show the front and rear view of eleven racks comprising the frequency division equipment installed on the two legs of the triangle at New York. Another photograph (Figure 5) is a close-up view of the newly designed repeater bay in this row where the jack field, intercom, pilot channel and miscellaneous test equipment are located. A test leak circuit and amplifier is provided for listening on a loud-speaker or for measuring on a db meter the levels on the working circuits at any pair of jacks in the voiceband and block circuits. The terminal at Pittsburgh is identical to that at New York. The equipment at Tenley Tower differs from that at New York and Pittsburgh in that the only frequency division terminal equipment installed is for the 8-bands on Block 1 of each leg with Block 2 provided for fallback. Blocks 3, 4, 5 and 6 are by-passed through a passive filter thus eliminating any possibility of carrier equipment failure in the fallback circuit at this station.

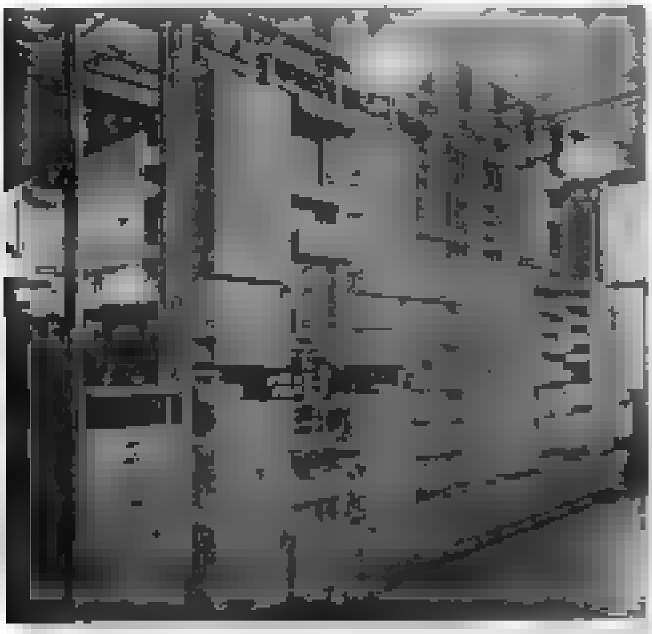

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Figure 3. Front view of rack row, New York terminal of WN2.1 carrier system

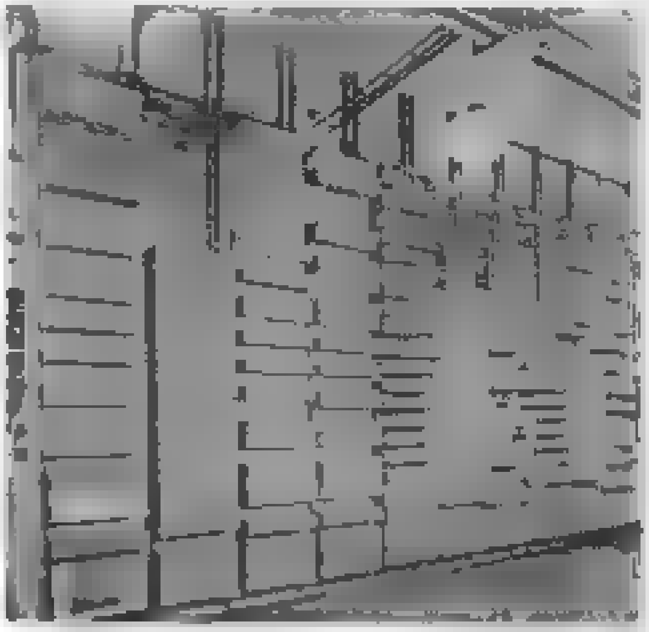

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Figure 4. Rear view of rack row, New York terminal of WN2.1 carrier system

Carrier Supply of WN2 is Used

Since the WN2.1 system terminals at New York and Pittsburgh are a combination of a portion of WN1 and a portion of WN2, it seemed desirable to tie in the carrier supply for the WN1 with that of the highly stable supply furnished by the WN2. A Frequency Divider 8047 was designed to provide the 600-cycle base frequency for the WN1 by subdividing the 3600-cycle base frequency generated by the WN2 which is controlled by a 151.2-kc crystal oscillator that holds constant within a fraction of one cycle. A photograph (Figure 6) shows the physical comparison of this divider with the Oscillator 29 just beneath it. The oscillator was formerly used to provide the 0.6-kc base frequency from which the various carrier supply frequencies were generated for the 8-band blocks at New York and Pittsburgh. Since there is no WN2 equipment at Tenley Tower, the Oscillator 29 is still in service at that point.

Pilot channels operate continuously on Block 1 of each beam to give an audible and visual warning of failure. The pilot channel goes along with the 8-bands over the fallback Block 2 when the diversity patch is made and thus predicts the continuity of the fallback route over this block. Another pilot channel operates continuously over Block 3 in the spectrum at 144 kc on both the regular and diversity routes between New York and Pittsburgh to give an audible and visual warning of failure over either route. The increase or decrease in pilot levels is detected by meter relays.

These pilot channels are also used to set the carrier supply frequencies at Pittsburgh and Tenley Tower exactly in synchronism with those at New York

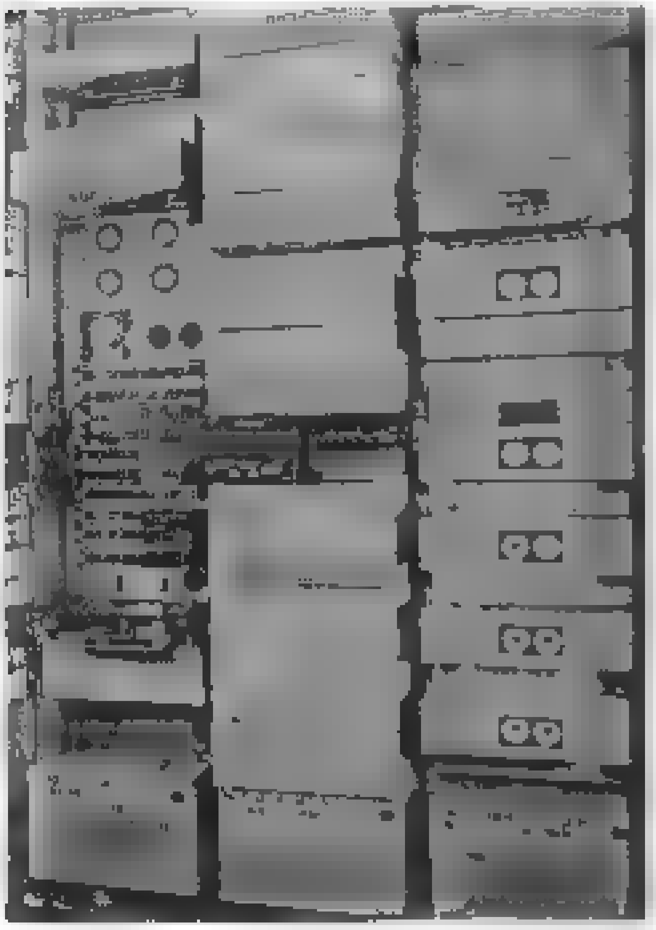

Figure 5. Close-up view of repeater bay, New York terminal of WN2.1 carrier system

An intercom set operates in the unmodulated half of band A located in the baseband spectrum frequencies from 0.3 to 1.7 kc around all three legs of the triangle. This arrangement provides not only communication but an excellent audible indication of radio trouble on any of the three legs over which 1-mc circuits are traversing to carry the 32 voicebands of traffic intelligence.

New York-Philadelphia System Improved Also

The carrier equipment for the two beams (RB1 and RB2) between New York and Philadelphia were also included in this improvement program and whereas they were formerly carrying only 8 voicebands they are now equipped to carry 16. The equipment is arranged so that diversity transmission of one group of 8-bands is over Block 1 of each beam and another group of 8-bands is over Block 2 of each beam, thereby providing the receiving terminal attendant with a choice of two beam

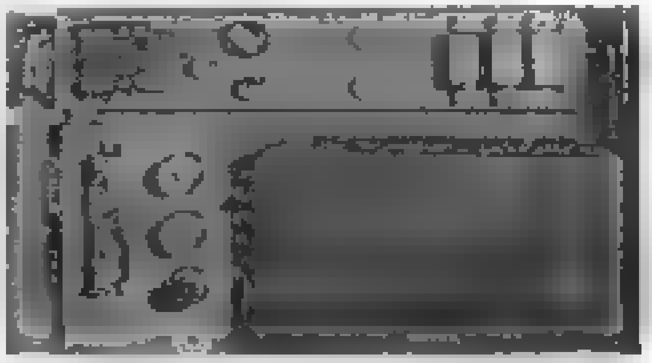

Figure 6. Frequency Divider 8047-A above an Oscillator 29-A

routes and two sets of carrier terminal block equipment. Blocks 1 and 2 lie in the baseband spectrum in the same place as described for the triangle beams RB3, RB4 and RB5. Thus similar features described for the triangle have been applied to these parallel beams between two stations. The repeater bay resembles very closely that shown in Figure 5 for RB3 and RB4 except the intercoms are omitted. The voiceband modulators and carrier supply bays are also like those shown in Figures 3 and 4 for voicebands 301 to 308, and 401 to 408. This new system called WN1.1 is partially illustrated by Figure 7.

The justification for an increase in the beam capacity to 32 bands between New York and Pittsburgh is partly the need for band-patching some of the traffic load from Philadelphia through New York and on over the beams to Pittsburgh.

The method of combining the modified types (WN1 and WN2) of carrier equipment has proven satisfactory during the past year of service. When the beam systems went into service it was contemplated that they would carry up to 32 voicebands, each loaded with 20 teleprinter channels. It is very gratifying to be able to report that this is now a reality. The signal-to-crosstalk performance with 32 voicebands, each loaded with 20 teleprinter channels, shows an improvement over the old arrangement with a 16-voiceband load. As each of the 640 teleprinter circuits is derived by standard Western Union FM channel terminals, 640 different channel

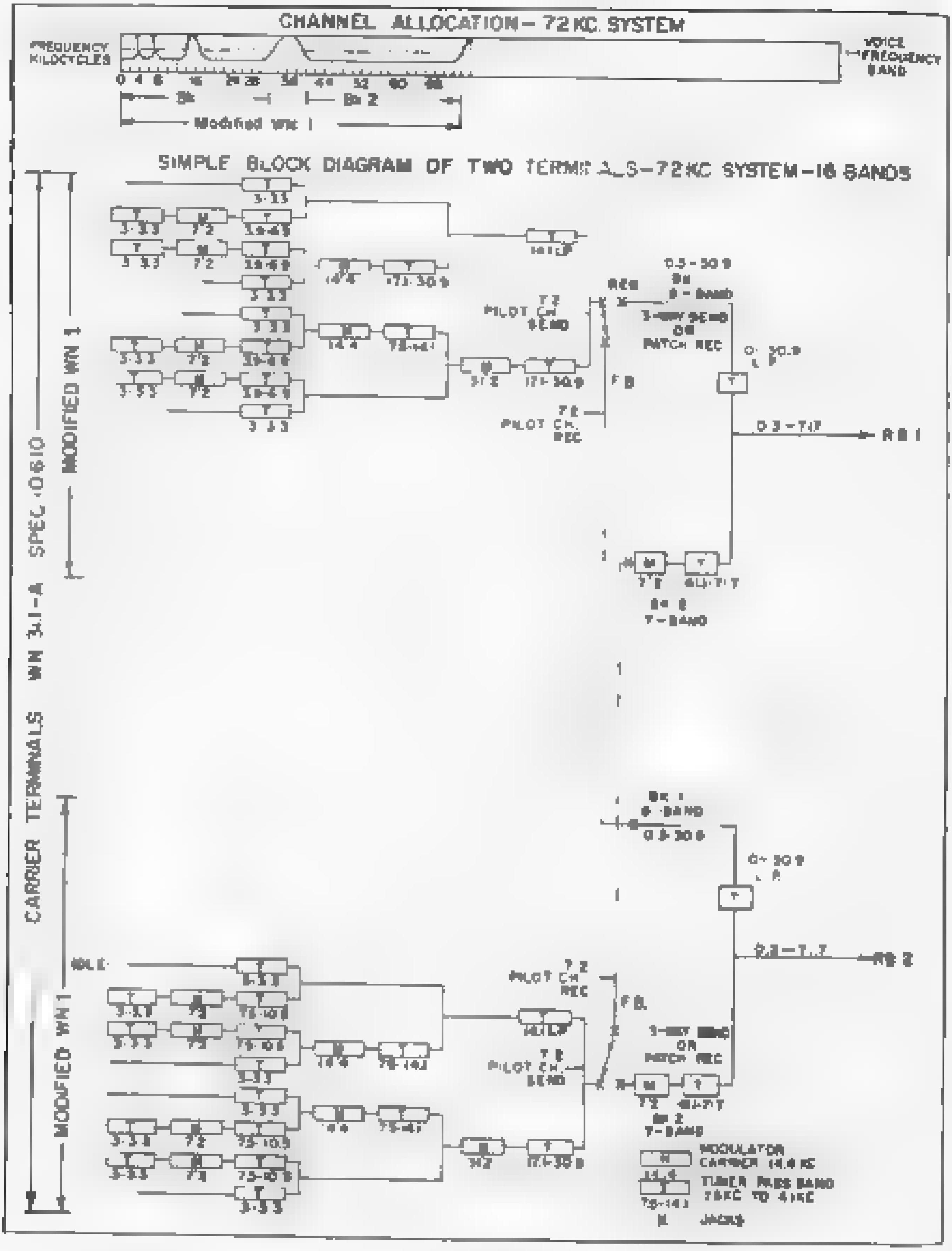

Figure 7. Two terminals theory for carrier system WN1.1

frequencies are transmitted over the system 100 percent of the time. This is the first time to our knowledge that a load of this nature has been carried on a radio relay system with a satisfactory signal-to-noise and crosstalk ratio.

Reference

1. A 150 Kilocycle Carrier System for Radio Relay Applications, J.E. Boughtwood, *Western Union Technical Review*, Vol. 2, No. 2, April 1948

Ralph R. Gose graduated from Virginia Polytechnic Institute in June 1930 and immediately thereafter joined the Research Division of Western Union. His activities there included studies of various phases of direct current, carrier and telephone signal transmission. His development of various equipment related to these activities resulted in two patents being assigned to the company. In 1943 he became associated with the newly organized Applied Engineering Department in charge of field applications of carrier systems for leased voiceband, wire line and radio beam. The present wire line E System, 10-Channel Terminal Bay for voicebands and WN Carrier Systems on the Radio Beam are part of these applications. Mr. Gose is presently supervising a carrier group in the Electronics Applications Engineer's office engaged in combining standard carrier apparatus in new ways to meet new service demands. In some projects this involves major changes in the old standards and creation of entirely new components.

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Simplified Design of Small Extension Springs

Although small helical springs are in use by the millions as essential components of telegraph devices, there is some lack of understanding of their design characteristics. An exploration in this unfamiliar field may prove to be a stimulating experience.

Springs are made in a wide variety of coiled and flat forms depending upon the purpose and the particular characteristics desired. Helically wound springs are basically of three types, compression, torsion and extension, but most of the helical springs used in record telecommunication equipment are of the latter type.

Almost all of the springs used in the electromechanical equipment employed by the telegraph industry are very small as compared to springs used in most other industries. While there is ample literature available on the design of springs, most of the tables and nomographs published to facilitate the calculations associated therewith cannot be used as aids in designing very small springs. In order to fill the need for data on small extension springs and to eliminate much of the laborious calculations involved in their design, the method described here was developed. This method can be used successfully for most of the spring design work encountered in telegraph apparatus, since a large majority of such springs are straightforward extension springs with standard end loops. Inasmuch as this method is particularly intended for engineers who design springs infrequently, a complete review of the fundamentals of extension spring design is presented. This article deals exclusively with springs made from music wire but the procedures described herein are applicable to all spring materials with some modifications.

Many of the springs used in telegraph apparatus are subjected to millions of loading cycles per month in normal operation. Even when a spring is originally designed for much less severe service than this, it eventually becomes a stock part and thus likely to be used for other purposes where it will be subjected to severe service. For this reason, most springs designed for use by Western Union should be designed with sufficient resistance to fatigue to withstand hundreds of millions of loading cycles. While this results in increased cost of manufacture, the difference is insignificant in small extension springs where the cost of material represents a relatively small percentage of the total spring cost.

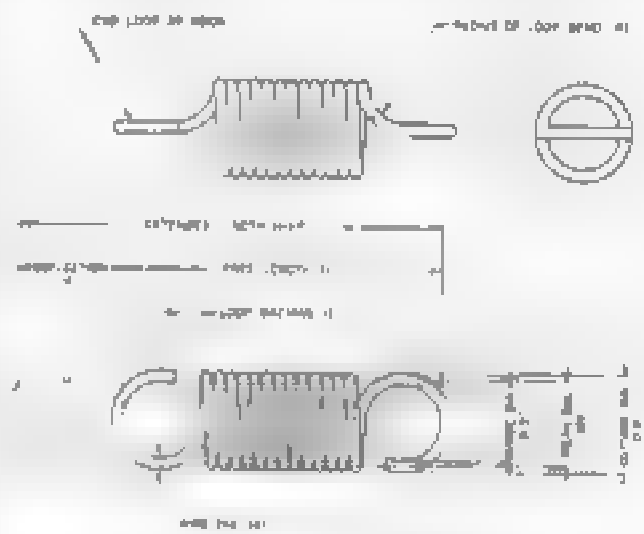

Figure 1 Spring nomenclature

Extension Spring Nomenclature

Figure 1 shows an extension spring with various terms used in spring design illustrated. The symbols used in spring design equations are given in Table I. Other terms commonly used in spring design are: (1) The *rate* or *gradient* of a spring is the change in load per inch deflection after the initial tension has been over-

TABLE I
SYMBOLS USED IN SPRING DESIGN EQUATIONS

C	— Spring index — D/d
d	— Wire diameter, in inches
D	— mean diameter — $OD - d$, in inches
f	— Deflection per coil, in inches
F	— Total deflection = Nf, in inches
F_{min}	— Minimum recommended deflection
F_2	= Deflection at the fatigue-limit load
G	= Rigidity modulus of steel in shear = 11,500,000 p.s.i. for music wire
H	= Free length inside end loops, in inches
ID	— Inside diameter — $OD - 2d$
K	= Wahl correction factor for correcting for stress due to curvature
L	= Extended length inside the end loops, in inches
N	— Total number of turns
OD	= Outside diameter — $D + d$
P	= Axial load, in pounds ($P = P_1 + P_{i.t.}$)
P_1	— Load required to extend a spring F inches after the initial tension has been overcome, in pounds
$P_{i.t.}$	= Load required to overcome initial tension, in pounds
P_2	= Load required to extend a spring to its fatigue limit, after initial tension has been overcome, in pounds
P_m	= Maximum possible load without exceeding fatigue limit stress ($P_m = P_2 + P_{i.t.}$)
P_{min}	= Minimum recommended load of a spring
p.s.i.	— Pounds per square inch
S_{it}	— Stress due to initial tension, in p.s.i.
S_m	— Corrected fatigue limit stress — $S \div K$
S_t	= Total fibre stress in shear due to initial tension plus elongation, in p.s.i.
S_f	= Stress due to elongation of spring, in p.s.i. ($S_f = S_t - S_{i.t.}$)
π	— Pi — 3.14

come; (2) The *working load* is the maximum load normally applied to the spring. (3) The *working length* is the extended length of the spring when the working load is applied. *When a spring is used for several different purposes, as is common in the telegraph industry, the working load and the working length will, of course, be different for each application.*

Initial Tension

In an extension spring, initial tension is the tension which holds adjacent coils of the spring together; it is wound into the spring during the coiling operation. When load is applied to the spring, this initial tension must be overcome before the coils

TABLE II - SPRING DESIGN EQUATIONS

A. BASIC SPRING EQUATIONS

(1) $$S_t = \frac{8PD}{\pi d^3} = \frac{2.55PD}{d^3}$$

(2) $$f = \frac{8PD^3}{Gd^4} = \frac{.695PD^3}{d^4 \times 10^6}$$

NOTE: $G = 11.5 \times 10^6$ FOR MUSIC WIRE

B. EQUATIONS DERIVED FROM (1) & (2)

(3) $$f = \frac{\pi S_f D^2}{Gd} = \frac{273 S_f D^2}{d \times 10^6}$$

(4) $$d^2 = \frac{8PC}{\pi S}$$

(5) $$P_1 = \frac{FGd^4}{8D^3N} = \frac{1.437Fd^4 \times 10^6}{D^3N}$$

(6) $$P_m = \frac{\pi S_m d^3}{8D} = \frac{.393 S_m d^3}{D}$$

C. SPECIAL EQUATIONS FOR EXTENSION SPRINGS

(7) $$S_f = S_t - S_{it}$$

(8) $$L = H + Nf$$

(9) $$H = (N+1)d + 2(D - d)$$

(10) $$N = \frac{L - 2D + d}{d + f}$$

start to separate. A thorough understanding of initial tension and the stress produced by it is essential for intelligent design of close-wound extension springs.

Initial tension is wound into a spring during the coiling operation by bending the wire away from the plane it will occupy in the finished spring. This produces a slight twist in the wire and causes each coil to spring back against the adjacent coil. The amount of initial tension wound into a spring can be controlled within limits which are determined by the spring index. When initial tension is wound into a spring, stress is produced in the wire. The stresses due to initial tension which can be conveniently wound into a spring by means of automatic spring winding equipment are shown in Table III, which indicates the maximum, minimum, and recommended stresses due to initial tension for various spring indexes. While the limits shown in the table can be exceeded by using special coiling operations, this is undesirable and should be avoided.

TABLE III. INITIAL TENSION STRESS AND WAHL CORRECTION FACTOR FOR VARIOUS SPRING INDEXES

SPRING INDEX	STRESS DUE TO INITIAL TENSION — MAXIMUM	RECOMMENDED	MINIMUM	WAHL CORRECTION FACTOR
4	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]

Initial tension is desirable in an extension spring for a number of reasons, the most important being that it permits more accurate control of the free length of the spring by eliminating clearance between adjacent coils. Initial tension permits closer tolerance to be used on the load requirement, since the amount wound into a spring can be varied somewhat. Initial tension also prevents unwinding of a spring during handling or shipping and greatly reduces tangling when a number are stored together in a bin or shipped together in a container.

When load is applied to an extension spring, the first part of the load is used to overcome the initial tension. Once overcome, however, initial tension does not affect the spring rate; it merely increases by a fixed amount the load required to extend the spring to any working length.

The value of initial tension wound into a spring should be chosen carefully by the designer. For a close-wound extension spring, this value should be at least 10 percent of the working load to be applied to the spring.

Spring Index

The ratio of the mean diameter of a spring to the wire diameter is called the spring index, or simply the index. It is possible to wind springs having indexes varying from about 4 to about 16, but wherever possible the index should be between 6 and 10. Most experts regard 9 as the optimum index. A spring having a large index is sometimes referred to as a "soft" spring, while one having a small index is sometimes called a "hard" or "stiff" spring.

When wire is formed into a spring by coiling, the inside portion of the wire is compressed and the outside portion is stretched. The amount of stress set up in the wire by this operation depends upon the curvature of the wire of which the spring index serves as a practical measure. The stresses set up in the wire by this curvature do not affect the rate of a spring, nor do they alter the load required to extend the spring a given length. The stress due to this curvature produces greater stresses on the wire on the inside of the spring than on the outside. However, this is important only in determining the maximum safe average stress for a given spring. Stress correction factors developed by A. M. Wahl are generally used in correcting for stress due to curvature. Values of the Wahl correction factor for various spring indexes are included in Table III. Use of these factors will be described later.

End Loops

There are many different types of hooks, or loops, formed on extension springs to connect the applied load to the spring and to anchor the fixed end of the spring. The types most commonly used in telegraph apparatus are formed by bending a full loop of the spring.

Two different types of end hooks formed from a full end loop are illustrated in Figure 2. The type shown in Figure 2b is usually called an across-the-center end loop, also known as a "crossover" or "crossed-center" end loop. This is the type of end loop or hook formed by the loop-forming pliers widely used to produce end loops manually in small extension springs. It is probably the least expensive of all end loops to form and for this reason it

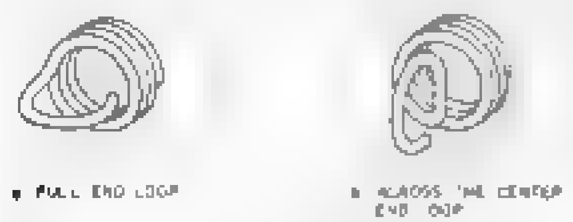

Figure 2. Commonly used end loops

is also the most widely used, especially in small springs. It is quite satisfactory for springs used in light duty or even in moderately severe service where conservative stresses are employed. However, it is not desirable in springs which must withstand hundreds of millions of cycles of operation because of the stress concentration present in the sharp bend produced by bending the end loop across the center of the spring.

Since most extension spring breakage occurs at the end loops, it is essential that the stress in these loops be kept low. The full end loop illustrated in Figure 2a avoids the stress concentration set up in the crossover end loop while retaining the advantage of a full end loop. The radius of bend of the end loop should be approximately one-half the inside diameter of the spring so that the curvature of the end loop will not be greater than the curvature of the other coils of the spring. This type of end loop is inexpensive to form and easy to install on a round spring post such as is commonly used in telegraph apparatus. The loop opening for this type of end loop should be approximately one-third to one-half the mean diameter of the spring.

Extension springs are sometimes subject to oscillation when the rate at which the load is applied approaches the natural frequency of the spring. The effect of such oscillations is to increase the effective deflection of the spring and thus increase the stress in the wire. In small extension springs it is often possible to eliminate these oscillations by inserting a felt wick or oiler in the spring to dampen the vibrations. When across-the-center loops are used, a felt wick cannot be readily inserted in the spring, which is another reason why full end loops are desirable.

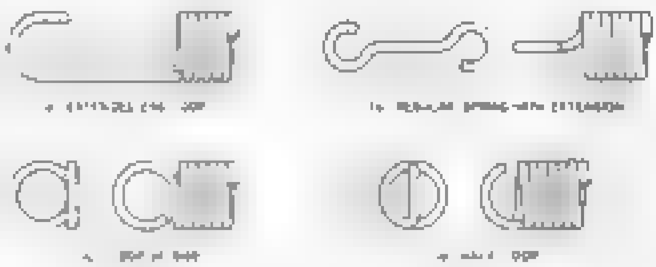

Figure 3. Special end loops

Several types of special end loops are illustrated in Figure 3. Such loops are occasionally necessary, but their use should be avoided wherever possible since special end loops usually limit the use of a spring to one application and/or increase the cost. When it is necessary to use a spring having an extended end loop like the one shown in Figure 3a, it is usually possible to substitute an extension arm and a standard spring, as shown in Figure 3b.

Spring Design Equations

The equations used in designing extension springs are given in Table II. Equations 1 and 2 are the two fundamental spring equations. Equation 3 is derived from the first two by solving for P in each equation, then equating the two and simplifying. Equation 4 is derived from Equation 1 by substituting C for D/d. Equation

TABLE IV - FATIGUE LIMIT STRESS OF MUSIC WIRE

WIRE DIA. IN INCHES	FATIGUE LIMIT STRESS, IN P.S.I.
0.005 TO 0.030	85,000
0.031 TO 0.050	80,000
0.051 TO 0.080	75,000
0.081 TO 0.125	70,000

5 is derived from Equation 2 by substituting F/N for f and P_1 for P and solving for P_1. *Note that Equation 2 applies for any value of applied load after the initial tension has been overcome, that is, P_1 or P_2 may be used in this equation to solve for the deflection per turn caused by a given load after the initial tension has been overcome* Likewise, Equation 6 is derived from Equation 1 by substituting the corrected fatigue limit stress, S_m, for S, and and Equation 10 was derived from these two by solving each equation for H, then equating the two and solving for N Equations 9 and 10 apply only to extension springs with full end loops.

The maximum safe fatigue stress for music wire of various sizes is given in Table IV By assuming any value of load P and spring index C, the wire size to give this maximum safe stress can be calculated by dividing the fatigue-limit stress

TABLE V - RECOMMENDED WIRE SIZES FOR EXTENSION SPRINGS

REQ'D LOAD (P)	SPRING INDEX (D/d)									
	6		7		8		9		10	
	WIRE DIAMETER (d) IN INCHES									
	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
1 oz	—	—	—	—	006	—	006	—	007	005
2 oz	007	006	008	006	008	006	009	007	0 0	007
3 oz	009	007	0 0	007	0 0	008	0	008	0 2	009
4 oz	0 0	008	011	008	0 2	009	0 3	009	0 4	010
5 oz	0 2	009	0 3	009	0 4	0 0	014	010	0 5	01
6 oz	0 3	0 0	0 4	010	0 5	0 1	0 6	0 1	0 7	012
7 oz	0 4	0 0	015	011	0 6	0 2	0 7	0 2	0 8	0 3
8 oz	0 5	01	0 6	012	017	0 2	018	0 3	020	0 3
9 oz	0 6	012	0 7	012	018	013	020	014	.021	0 4
0 oz	0 6	0 2	0 8	013	0 9	014	02	0 4	.022	.015
oz	017	0 3	019	014	020	0 4	022	0 5	023	0 6
12 oz	0 8	0 3	020	0 4	021	0 5	023	0 6	024	0 6
1 lb	02	0 5	023	016	024	0 7	026	0 8	028	0 9
1 25 lbs	023	017	025	018	027	019	029	020	032	020
1 5 lbs	026	0 9	028	020	03	021	033	022	035	023
1 75 lbs	028	020	03	022	033	023	035	024	038	025
2 0 lbs	030	022	033	023	035	024	038	025	040	027
2 5 lbs	034	024	037	026	039	027	042	028	045	030
3 0 lbs	037	026	040	028	043	030	046	032	049	033
3 5 lbs	040	028	043	030	047	033	050	035	055	036
4 0 lbs	043	030	046	033	050	035	055	037	058	038
4 5 lbs	045	033	049	035	054	037	058	039	062	041
5 0 lbs	048	035	053	037	057	039	06	041	065	043
6 0 lbs	053	038	058	04	063	043	067	045	071	047
8 0 lbs	062	044	067	047	072	049	078	054	085	056
10 lbs	069	049	075	054	083	057	089	060	095	063
12 lbs	076	056	084	059	091	063	097	066	104	069

also substituting P_m, the load which will produce the fatigue limit stress in the wire, for P

Equations 7 through 10 are special spring equations which are used only in extension spring design. Equations 8 and 9 were derived from an analysis of Figure 1 by the Wahl correction factor and then substituting these values of P, S, and C in Equation 4. Thus, it is possible to prepare a table showing the minimum wire size which should be used for various values of load and spring index. The minimum

wire sizes shown in Table V were determined in this manner

The maximum wire size which should be used for a given load and spring index can also be determined, but the method used is necessarily more or less arbitrary. In determining the maximum wire sizes given in Table V, consideration was given to the problem of maintaining close load tolerances on small extension springs. A load tolerance of plus or minus 10 percent is usually used on Western Union spring drawings and is generally acceptable to spring manufacturers However, this tolerance is difficult to maintain at low values of total stress, where the initial tension load represents a relatively large percentage of the total load. The maximum wire sizes in Table V are such that the required load will produce an elongation in the spring equal to one-third of the total elongation from the free length to the fatigue-limit length of the spring These maximum wire diameters were determined as explained in the following paragraph.

If the maximum permissible wire diameter for a given load and spring index is used, this load will produce a minimum permissible stress in the wire. If it is assumed that this minimum stress should occur at an elongation equal to one-third of the elongation from the free length of the spring to the fatigue-limit length, the minimum stress can be calculated as follows

$$S_{min} = \frac{1}{3}\left(\frac{S}{K} - S_{i.t.}\right) + S_{i.t.}$$

Where S_{min} is the minimum stress and the other symbols are as shown in Table I.

The maximum wire diameter can now be calculated from Equation 4 by substituting the values of the minimum stress and assumed load for S and P in the equation.

While either the maximum or minimum wire size given in Table V may be used in designing a spring for a given load and a given index, it is desirable to choose a wire diameter which falls about midway between these two extremes. This will result in a well-proportioned spring in which the maximum stress developed due to the working load will be well below the fatigue limit of the spring The wire sizes shown in Table V are the calculated diameters, but, although music wire can be drawn to any specified diameter on special order, it is desirable to use the music wire gauge sizes shown on the nomograph in Figures 5 and 6.

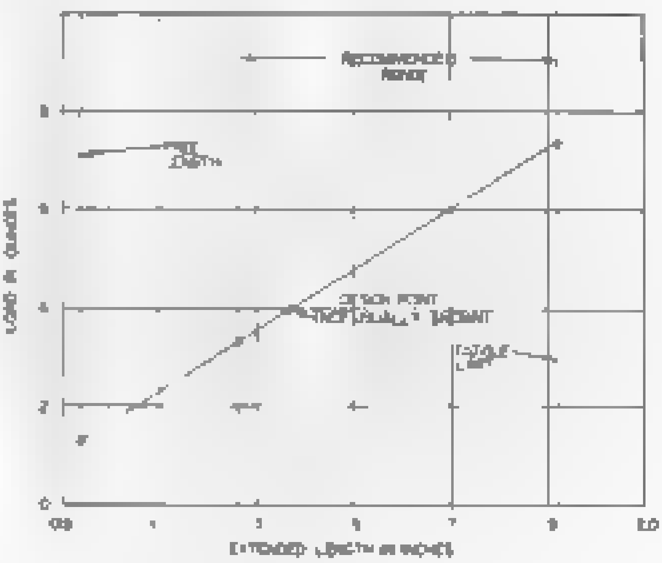

Figure 4. Load-extended length chart

Design Procedure

In designing springs for telegraph apparatus, the required load at a given extended length is usually known This extended length is, of course determined by the design of the apparatus in which the spring is to be used. Frequently it can be changed within limits by relocating spring posts or spring brackets associated with the spring. The required load at this length may be determined by the designer's experience on similar apparatus or by tests made in the laboratory on a model of the apparatus.

Once the required load at any extended length has been fixed, the wire diameter and mean diameter can be selected from Table V by assuming a spring index If there is no limit on the outside diameter of the spring an index of 8 or 9 should be assumed. If the maximum allowable diameter is limited, it may be necessary to resort to trial and error in determining the spring index and wire size from the table When the wire size and the index have been determined, the total stress in the wire due to the initial tension stress plus the stress due to the elongation of

the spring can be determined from Equation 1. The stress due to initial tension can then be chosen from Table III, and the stress produced in the wire by elongation of the spring can be determined from Equation 7.

The stress found by Equation 7 can now be substituted in Equation 3 to determine

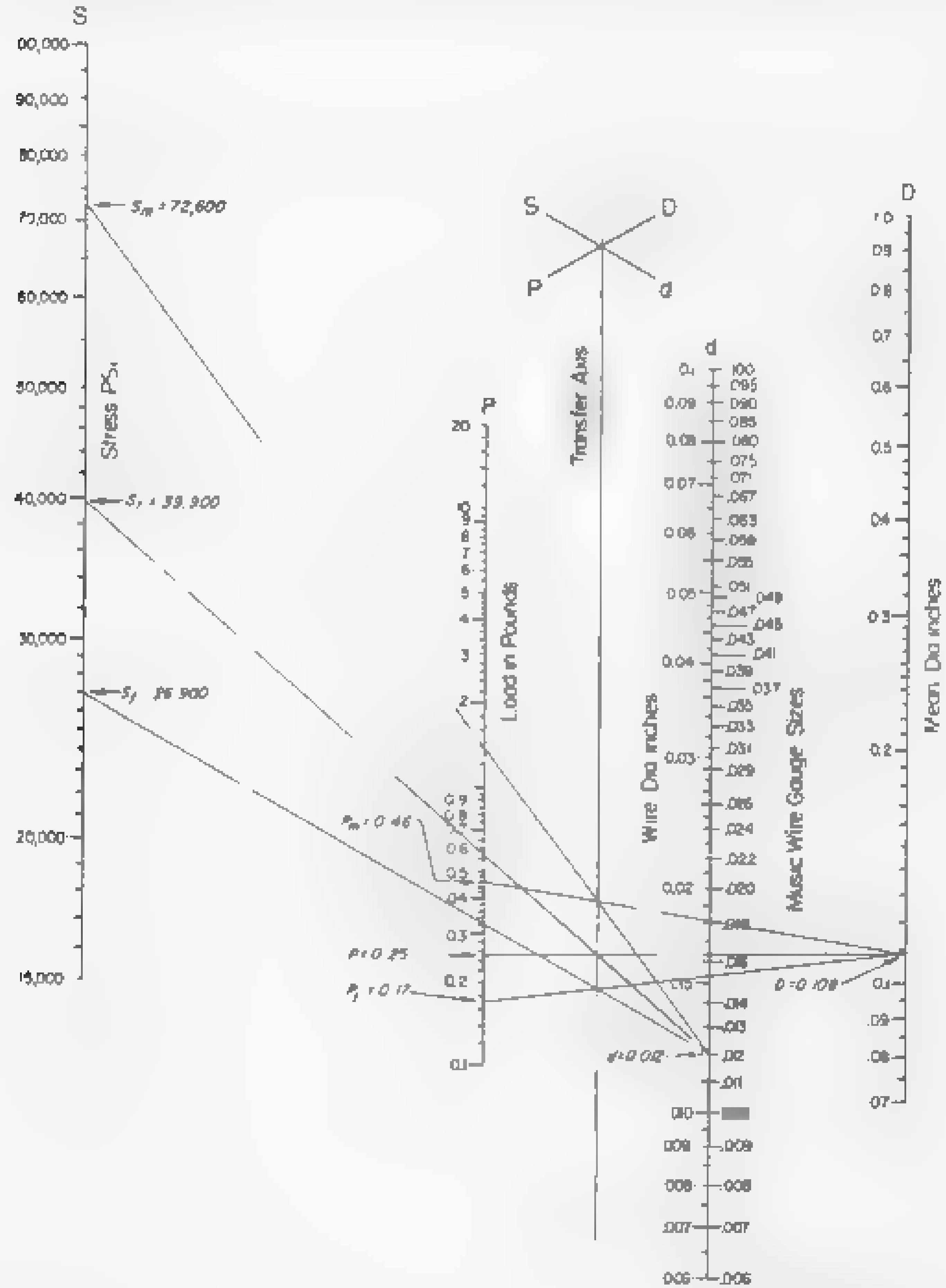

Figure 3. Spring design nomograph for calculations involving load, stress, wire diameter and mean diameter

the deflection per turn of the spring. The final step in designing a spring is to determine the number of turns and the free length of the spring. For a spring with full end loops, the working length, L, is given by Equation 8 and the free length, H, is given by Equation 9. The number of turns can be found from Equation 10 and this value of N can then be used to find the free length and the extended length of the spring from Equations 9 and 8, respectively.

Example

Assume that it is desired to design a spring to produce a 4-ounce load at an extended length of 1.375 in. and that the maximum permissible outside diameter is 0.125 in. First, assume a spring index of 9. From Table V, the wire diameter for a 4-ounce load and an index of 9 may vary from 0.009 in. to 0.013 in. Use a wire diameter of 0.012 in., which is a music wire gauge size, for a first trial. The mean diameter of the spring will be 9 × 0.012 in. = 0.108 in. The outside diameter will then be 0.108 in. + 0.012 in. = 0.120 in. Since this is below the maximum permissible diameter of the spring, both the wire diameter and the index are satisfactory. The total stress in the wire due to initial tension plus the deflection load can now be determined from Equation 1:

$$S_t = \frac{2.55PD}{d^3} = \frac{2.55 \times \frac{4}{16} \times 0.108}{(0.012)^3}$$

$$S_t = 39{,}900 \text{ p.s.i.}$$

From Table III, the recommended stress due to initial tension for a spring with an index of 9 is 13,000 p.s.i. The stress which should be produced in the wire by deflection due to a load of 4 ounces is, from Equation 7:

$$S_f = S_t - S_{it} = (39{,}900 - 13{,}000)$$

$$S_f = 26{,}900 \text{ p.s.i.}$$

The deflection per turn, f, can now be found from Equation 3:

$$f = \frac{0.273 S_f D^2}{d \times 10^6} = \frac{0.273 \times 26{,}900 \times (0.108)^2}{0.012 \times 10^6}$$

$$f = 0.00713 \text{ in. per turn}$$

From Equation 10 the number of turns, N, is:

$$N = \frac{L - 2D + d}{d + f} = \frac{1.375 - 2(0.108) + .012}{0.012 + 0.00713}$$

$$N = 61.2 \text{ turns}$$

$$(\text{use } N = 61 \text{ turns})$$

NOTE: For a spring with end loops at right angles to each other, the number of turns should be chosen to the nearest quarter or three quarters of a turn. For a spring with end loops in the same plane, the number of turns should be chosen to the nearest half or whole number of turns.

The free length, H, can now be calculated from Equation 9:

$$H = (N + 1)\,d + 2\,(D - d)$$

$$= (61 + 1)\,0.012 + 2\,(.108 - .012)$$

$$H = 0.936 \text{ in.}$$

The total deflection of the spring at the working load is (1.375 − 0.936) = 0.439 in.

Load-Extended Length Chart

Although the design of the spring has now been completed, a load-extended length chart for it should be constructed. The calculations necessary for constructing the chart will serve as a check on previous calculations. The chart, which must be included on every Western Union spring drawing, will also make it easier to check the spring for possible use in future applications.

The first step in constructing such a chart is to calculate by Equation 5 the load required to produce the total deflection after the initial tension has been overcome. The load necessary to overcome initial tension can then be determined by subtracting this load from the total required load. Two points on the load-extended length chart can then be determined: (1) the load, $P_{I.T.}$, required to overcome initial tension, i.e., the load at zero deflection; and (2) the load, P_1, at the working length; i.e., the load required to produce a deflection of F inches after initial tension has been overcome.

The maximum safe load which can be applied to the spring should then be calculated. This can be done by finding the fatigue limit stress from Table IV, dividing this stress by the Wahl correction factor found from Table III, and then using this

stress to find the fatigue limit load from Equation 6. As a check on previous calculations, the deflection at this load should be calculated by subtracting $P_{1.5}$ from this load and then substituting the result in Equation 5 and solving for F.

As an example of the foregoing, suppose it is desired to construct a load-extended length chart for the spring designed in the example previously given. From Equation 5

$$P_1 = \frac{1.437 F d^4 \times 10^6}{D^3 N}$$

$$= \frac{1.437 \times .439 \times (.012)^4 \times 10^6}{(.108)^3 \times 61}$$

$P_1 = 0.170$ lbs. $= 2.72$ ounces

And $P_i = P - P_1 = 4 - 2.72 = 1.28$ ounces

From Table IV, the fatigue limit stress for 0.012-inch diameter music wire is

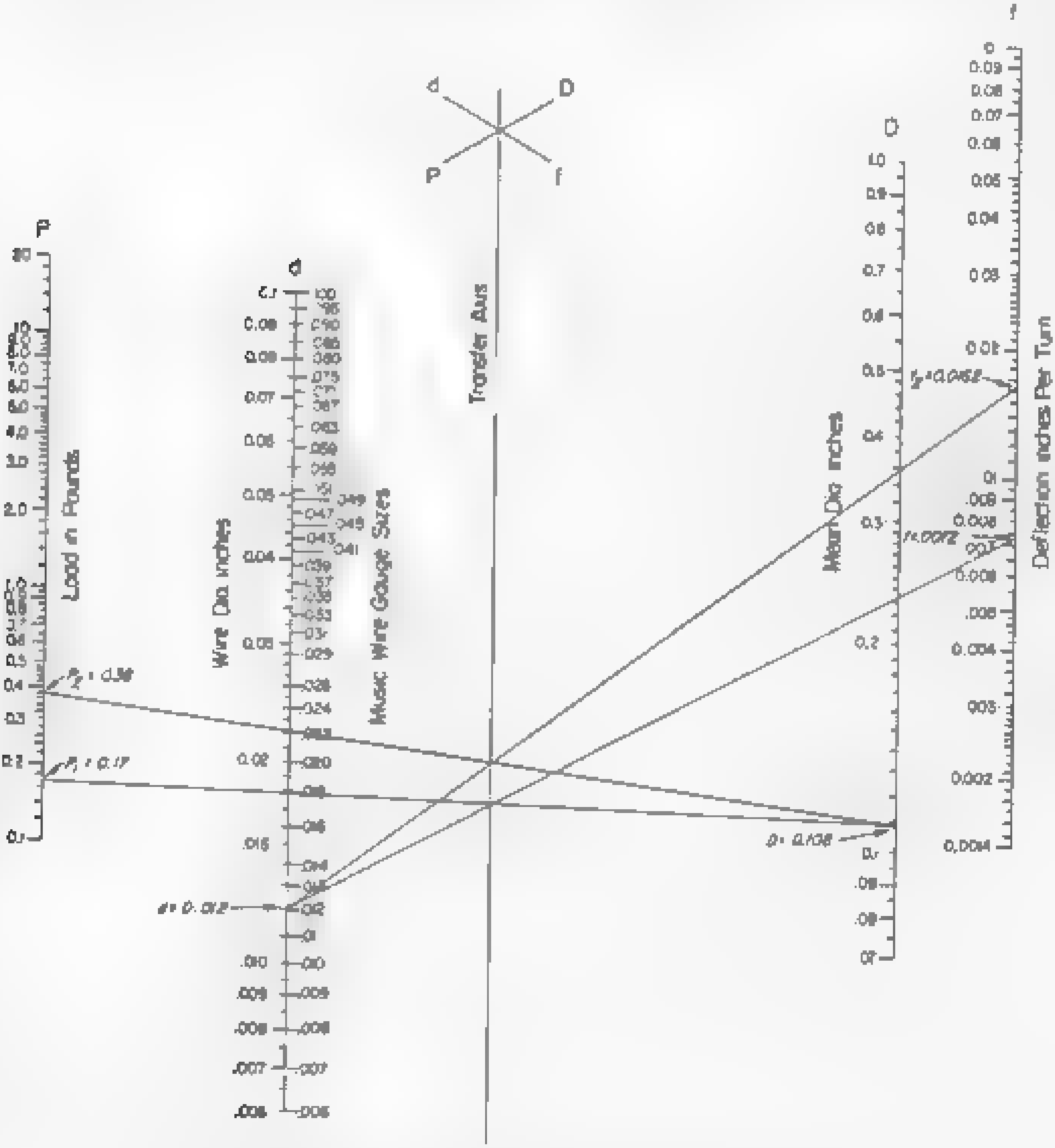

Figure 6. Spring design nomograph for calculations involving load, wire diameter, mean diameter, and deflection per turn.

85,000 p.s.i. From Table III, the Wahl correction factor for a spring index of 9 is 1.16. The maximum permissible stress due to load plus initial tension is then 85,000 $\div$ 1.16 = 73,300 p.s.i. Substituting this value in Equation 6 and solving for P_m gives

$$P_m = \frac{0.393 \times 73{,}300 \times (.012)^3}{0.108}$$

$$P_m = 0.461 \text{ lbs} = 7.38 \text{ ounces}$$

The load, P_2, required to deflect the spring to its maximum safe length is: $P_2 = P_m - P_{i.t.} = (7.38 - 1.28) = 6.10$ ounces. Substituting this value in Equation 5 and solving for F_2, the deflection at this load, gives:

$$F_2 = \frac{8 P_2 D^3 N}{G d^4} = \frac{8 \left(\frac{6.10}{16}\right)(.108)^3 \times 61}{11.5 \times 10^6 \times (.012)^4}$$

$$F_2 = 0.982 \text{ in.}$$

It is more convenient to use a chart showing the extended length, rather than the deflection, plotted against the load. Such a chart can now be plotted, as shown in Figure 4, from the following data:

LOAD IN OUNCES	EXTENDED LENGTH IN INCHES $(H + F)$
$P_{i.t.} = 1.28$	0.936 (H)
$P = 4$	1.375 $(H + F)$
$P_m = 7.38$	1.918 $(H + F_2)$

Since the three points on the curve should fall on a straight line, the chart will serve as a check on the calculations.

The minimum working length at which the spring can be used without exceeding the plus or minus 10 percent tolerance on the load should be shown on the load-extended length chart. The deflection at this working length should be one-third of the total deflection from the free-length to the fatigue limit or six times the free-length tolerance given in Table VII, whichever is greater. For the example given, one-third of the total deflection is 0.982 $\div$ 3 = 0.327 in. Six times the free-length tolerance from Table VII is 6 $\times$ 0.031 = 0.186 in. Thus, a line should be drawn on the chart at a deflection of 0.327 in. to indicate the minimum recommended working length of the spring, as shown in Figure 4. Although the spring can be used at deflections below this point, the load tolerance cannot then be reliably held to plus or minus 10 percent. The minimum recommended load at this point is given by,

$$P_{min} = \frac{F_{min}}{F_2}(P_m - P_{i.t.}) + P_{i.t.}$$

$$= \frac{0.327}{0.982}(7.38 - 1.28) + 1.28$$

$$= 3.31 \text{ ounces}$$

Tolerances

The final step in preparing a manufacturing drawing for a spring is to select tolerances for the outside diameter, free length, number of turns, and the required load. The tolerances specified should be readily obtainable on automatic spring winding machines. Tables VI and VII show tolerances for the outside diameter and free length which have been agreed upon by many manufacturers. Tolerances closer than those given in the tables should be avoided wherever possible.

TABLE VI - TOLERANCES ON OUTSIDE DIA OF EXTENSION SPRINGS

OUTSIDE DIA IN INCHES	PLUS OR MINUS TOLERANCE
UP TO 1/8	0.003"
OVER 1/8 TO 3/16	0.004"
OVER 3/16 TO 1/4	0.006"
OVER 1/4 TO 3/8	0.008"
OVER 3/8 TO 1/2	0.010"
OVER 1/2 TO 3/4	0.012"
OVER 3/4 TO 1	0.015"

The tolerance on the number of turns should be 5 percent of the number of turns to the nearest one-half turn with a maximum tolerance of two turns. Tolerances on the diameters of music wire are covered in ASTM (American Society for Testing Materials) No. A-228 and need not be specified on the drawing. Tolerances on the test load or loads should be 10 percent. Tolerances on the radius of the loop bend and on the loop opening should be at least

TABLE XIII · TOLERANCE ON FREE LENGTH OF EXTENSION SPRINGS

FREE LENGTH	PLUS OR MINUS TOLERANCE
UP TO 1/2"	0.015"
1/2" TO 3/4"	0.020"
3/4" TO 1"	0.031"
OVER 1"	.047" +.015" FOR EACH ADDITIONAL 1" OF LENGTH

15 percent of the nominal dimensions or at least 0.010-inch, whichever is greater.

The manufacturing drawing for the spring designed in the example given should include, in addition to the load-extended length chart, the following information

Material: Steel music spring wire (ASTM No. A-228).

Wire diameter, d = 0.012 in.

Mean diameter, D = 0.108 in.

Outside diameter, OD = 0.120 in. ± 0.003 in.

Number of turns, N = 61 ± 2

Free length, H = 0.938 in. ± 0.031 in

Radius of loop bend, R = 0.047 in. ± 0.010 in.

Loop opening = 0.047 in. ± 0.010 in

Type of end loops = Parallel

Direction of winding = Either

TEST DATA

Length ($H + F$)	Load in ozs.
1.263	3.31 ± 1/3
1.918	7.38 ± 3/4

Use of Nomographs

Numerous tables and nomographs have been published in the literature on spring design to reduce the calculations involved in designing springs. For example, tables are available which show the square, cube and fourth powers of the wire diameters of all commonly used sizes of round wire. However, the most useful tool for reducing the labor involved in spring calculations is the nomograph, which is a graphical representation of an equation. Unfortunately, all of the nomographs published to date are intended for use in designing large springs and they do not include the very small wire diameters and loads so often used in springs for telegraph apparatus. For this reason, two nomographs published by The American Steel and Wire Division of U. S. Steel have been modified to fit the types of springs normally used in Western Union. These nomographs are shown in Figures 5 and 6. They are simple and easy to use and are sufficiently accurate for most spring design problems

The spring design procedure already described can be used in conjunction with Figures 5 and 6 to design extension springs rapidly and correctly. Each of the two nomographs has four scales and a transfer axis. To determine any one value on either nomograph, it is necessary to know the values along the other three scales. The nomographs have a symbol along the transfer axis which indicates the scales between which lines are always drawn e.g., suppose it is desired to determine the average stress produced in the wire of a spring of mean diameter, D, and wire diameter, d, when a load in pounds, P, is being exerted by the spring. A line is first drawn between the appropriate values on the P and D scales. Then through the wire diameter on the d scale and the intersection of the $P - D$ line with the transfer axis, a second line is drawn and extended to the S scale. The intersection of this line with the S scale will give the average stress in the wire, uncorrected by the Wahl factor for the increase in stress at the inside diameter of the spring.

To illustrate the use of the nomographs, the spring problem previously solved by means of the spring equations will be solved by means of the nomographs:

Outside diameter (O.D.)	=	0.120 in
Wire diameter (d)		0.012 in
Mean diameter (D)		0.108 in
Spring index (C)		9
Required load (P)		4 oz = 0.25 lb
Working length (L)		1.375 in
Initial tension stress ($S_{i.t.}$)		13,000 p.s.i.
Wahl correction factor (K)	=	1.17
Corrected fatigue limit stress (S_w)	=	72,600 p.s.i.

Using Figure 5, draw a line from $P = 0.25$ lbs. to $D = 0.108$ in. Through the intersection of this line with the transfer axis and $d = 0.012$ draw a line to the S scale and read the total stress, $S_t = 39,900$ p.s.i.

The stress due to deflection alone is:

$$S_f = S_t - S_{i.t.} = 39,900 - 13,000 = 26,900 \text{ p.s.i.}$$

To determine the load produced by the deflection stress, S_f, use Figure 5 and draw a line from $S_f = 26,900$ to $d = 0.012$. Through the intersection of this line with the transfer axis and $D = 0.108$, draw a line to the P axis and read $P_1 = 0.17$ lbs.

Knowing $P_1 = 0.17$, $D = 0.108$ and $d = 0.012$, the deflection per turn to produce the design load is determined in a similar manner from Figure 6 as $f = 0.0072$ inches per turn.

The number of turns and free length are calculated as before, from Equations 10 and 9 respectively

$N = 61$ turns

$H = 0.936$ in

With $S_w = 72,600$, $d = 0.012$ and $D = 0.108$, from Figure 5 $P_w = 0.46$ lbs

The load resulting from the initial tension stress of 13,000 p.s.i. is:

$$P_{i.t.} = P - P_1 = 0.25 - 0.17 = 0.08 \text{ lbs}$$

Therefore the load required to extend the spring to its maximum safe length is.

$$P_2 = P_w - P_{i.t.} = 0.46 - 0.08 = 0.38 \text{ lbs}$$

The deflection per turn, f_2, at the fatigue limit is determined from Figure 6. $P_2 = 0.38$, $D = 0.108$, and $d = 0.012$, then $f_2 = 0.0162$ inches per turn

The total elongation of the spring at the fatigue limit is, therefore,

$$F_2 = f_2 N = 0.0162 \times 61 = 0.988 \text{ in}$$

The values obtained by means of the nomographs do not agree exactly with the precise method of calculating from the spring equations, however, the percentage of error is small and the accuracy adequate for most of the springs used in Western Union equipment

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P. F. Recca joined Western Union in 1948 while attending evening classes at the Polytechnic Institute of Brooklyn from which he obtained a degree of Bachelor of Mechanical Engineering in June 1952. For the last six years Mr. Recca has been associated with the Mechanical Equipment group of the Plant and Engineering Department as an Engineer engaged in the design and improvement of mechanical telegraph apparatus. He is a member of ASME and has an E.I.T. certificate from the New York State Board of Professional Engineers.

Mr. Smith's biography appeared in the October 1954 issue of TECHNICAL REVIEW

F. B. BRAMHALL, Transmission Planning Engineer

A Review of Proposed Carrier Systems For Data Transmission

A discussion of techniques for dividing 3-kc spectrum units into channels for telegraph circuits is of current interest because of the higher transmission speeds sought when such circuits are assigned as data processing facilities. Comment and straightforward comparison of existing and proposed systems proves enlightening in this review of the requirements for high speed transmission and of some of the work done in this field of telecommunications by IBM Corporation, Bell Laboratories, MIT Lincoln Laboratories, Sperry Rand Corporation and Western Union.

"DATA TRANSMISSION" interpreted literally doesn't carry any speed implication. The term is generally accepted as meaning the transportation of information used for record communication of business character other than discrete, separated messages. Gradually, however, perhaps by common usage, there seems to be a high-speed connotation attaching itself to the expression. It is proposed to discuss here principally these high volume, high rate, forms of record communication. Methods and characteristics of lower speed systems for data handling and message telegraphy will be outlined only as required for comparison and improved understanding of the newer systems.

Right away we find ourselves characterizing transmission systems as high-speed and low-speed. Perhaps a numerical border line between "high" and "low" will simplify this further discussion. High-speed systems, we might say, are those which operate above an information rate at which operators are expected to read, edit, or monitor the received material. This concept provides one very reasonable basis for a distinction between telegraphy and data transmission, although there is really no clear-cut distinction between the two. Message-by-message business information is generally read and edited before it is transcribed into such form as to go into an automatic business accounting device. In the form that "integrated data processing" is now growing, however, the privilege of reading and editing is afforded but the transcription to tape or punched card record is largely automatic. It may be that the term "data transmission" will come to designate a high-speed form of business communication in which the information is delivered directly to the business machine without any human intervention whatever.

With the advent of the wider use of self-checking codes[1] and other error-detecting and error-correcting methods, manual handling and human intervention will be less and less necessary. The modern business machine, be it electromechanical or fully electronic, is being designed to accept information at a high rate. The communication facility which brings information not required to be divided into discrete messages each with an address and a date and a signature can very properly run at a speed much higher than ordinary telegraph speed.

The final speed may well be dictated by the nature of the communication plant. The facilities plants of the "common carriers" are all built around the voiceband. Carrier telegraph systems, facsimile systems and wire-photo systems are mostly designed to be accommodated by a voiceband. It wasn't always so. Early carrier telegraph systems employed frequency allocations way up—as high as the designers' fancy dictated. Facsimile and photo methods were not always made for the voiceband. But now the 3-kc spectrum unit, generally accepted as standard for good telephone speech, is the recognized vehicle for record communication also.

Let us review briefly how the telephone voiceband is and has been used in telegraphy.

Narrow-Band Frequency-Division Techniques

The technique of dividing a voiceband into a number of narrower band channels for telegraphy is now often referred to as "frequency-division multiplexing." This term means simply that a wide unit of frequency spectrum is divided into a multiplicity of narrower units by frequency selective filter techniques. A considerable number of frequency-division patterns have evolved here and abroad, but only four appear to have attained any real status of standardization. The European system, designated as "standard" by the international telegraph systems committee, CCIT, spaces the channels 120 cycles apart and locates their centers on odd harmonics of 60 cycles. In other words, the nominal mid-channel frequencies are 300, 420, 540, and so forth, with as many channels as can be accommodated by the voiceband which is used as the vehicle.

The pattern used by AT&T and its associated companies for the TWX network and AT&T's private wire services uses channels spaced 170 cycles apart with the center frequencies located at odd multiples of 85 cycles. These locations are then 425, 595, 765, and so forth. In this system, a lower frequency channel is sometimes located at 255. This channel is likely to be of an inferior grade and frequently used as an order wire or in some low-speed signaling service. Counting this bottom channel, the 18th and last channel workable on the usual high-grade trunk facility band is located at 3145.

In the early 1940's, Western Union had already established a considerable network of channels designed for time-division multiplex telegraph working. These provided efficient circuits for 4-channel (4-printer time-division multiplex) service at any channel speed up to and including 70 or 75 wpm. Operated by frequency modulation, the nominal mid-channel frequency was raised 70 cycles to represent a spacing condition, and lowered 70 cycles to represent a marking condition. It could be said that these channels were designed for 70-cps service since at this rate the deviation, the sweep from mid-frequency in either direction, is equal to the maximum modulation rate. The carrier engineer describes this situation as a deviation ratio of unity. The only magic that attaches to it is the fact that an FM system employing a deviation ratio of unity results in a carrier-sideband relationship which makes efficient utilization of the available pass band.

The carrier-sideband pattern is similar to that which results when amplitude modulation (on-off keying) is used at the same intelligence rate. These channels are located at 450, 750, 1050 cycles and so forth, 300 cycles apart. These locations again are odd harmonics of half the channel separation. In other words, they are odd multiples of 150 cycles. The useful band within these channels is about 160 cycles. Here one gets an idea of the cost, in terms of spectrum, of dividing a wide unit into multiple narrower units. With 300-cycle separation and 160 cycles useful derived signaling range, the guard band (no man's land between channels) is 140 cycles or 47 percent. This index of spectrum usage is roughly the same for all the various systems.

With the advent of the reperforator switching method of working, time-division multiplexing fell into disuse and the once "standard" wide-band telegraph channel began to disappear. Today there are only enough of them left to accommodate those circuits used in telemeter service.

Our whole present-day network of carrier telegraph channels for private wire and message services is built from what we now know as narrow-band channels, 150 cycles apart and again located at odd harmonics of half the separation. These begin with the 5th harmonic of 75 cycles or 375, progressing upward through 525, 675, and so forth to 1575. 1575 is No. 9, and two 9-channel banks are operated in each of the two halves into which all voicebands are subdivided. Many circuits, to be sure, carry 20 channels, but this is accomplished by inserting channels at 1725 and 1875 between the two half-bands, or subbands, as we call them. All

of these channels are operated by frequency modulation with a deviation of ±35 cycles, indicating that they were designed for 35 cycles or a 70-baud intelligence rate. A number of considerations went into the choice of this channel separation and deviation but ticker speeds were already at 66 bauds at the time these standards were established and the possibility of 100-speed printer service particularly for private wire systems did not seem remote.

In Europe, with distances relatively short, possibly 120-cycle separation is satisfactory, but the requirements for high-quality transmission over great distances in this country pose a more difficult problem. Pertinent to this subject is the fact that one American railroad which has used 120-cycle spaced channels for a number of years is finding their transmission qualities inadequate for present-day high speeds. Contemplating the use of 10 characters-per-second transmission in a data transmission project, they are installing new telegraph channels on 150-cycle separation. On the other hand, the Telephone Company's wider separation no doubt seemed a good choice at the time because when their carrier telegraph was developed in the early 1920's, high quality channel filters for closer spacing would have been very costly, to say the least.

Until two or three years ago, Bell System installations were amplitude-modulated channels of a type designated by the number "40." Present installations, we believe, are entirely of the Type 43 which is operated by frequency modulation.

The following table of channel locations for the various voice-frequency carrier telegraph systems which have been widely used may serve a useful purpose:

EUROPEAN SYSTEM CCIT STANDARD 120 SEP.	AT&T SYSTEM & ARMED FORCES 170 SEP	WESTERN UNION WIDE-BAND 300 SEP	WESTERN UNION NARROW-BAND 150 SEP
300	255	450	375
420	425	750	525
540	595	1050	675
660	765	1350	825
780	935	1650	975
900	1105	1950	1125
1020	1275	2250	1275
1140	1445	2550	1425
1260	1615	2850	1575
1380	1785	3150	1725
1500	1955		1875
1620	2125		2025
1740	2295		2175
1860	2465		2325
1980	2635		2475
2100	2805		2625
2220	2975		2775
2340	3145		2925
2460			3075
2580			3225
2700			
2820			
2940			
3060			
AM or FM	AM — Type 40 FM — Type 43	FM	FM

It is generally agreed that Western Union is fortunate in having its whole network operated by the frequency-modulation method. Presently with data processing assuming such an important role in record communication, any minor refinement or reasonable expense for error freedom is probably very well justified, and it has been shown by all investigators that FM has at least a two-to-one advantage from the standpoint of extraneous interference, and a very great immunity to attenuation changes on the transmission medium or vehicle band.

Various projects in high-speed printing and in data transmission have from time to time caused a revival of interest in our old standard wide-band telegraph channel, 300-cycle spaced arrangement which divided the voiceband into ten parts. Some of these channels were recently installed in the International Department's ocean cable system. In this service, they handle 200 wpm. By a conservative rating, these channels are capable of handling 280 wpm which is 140 bits per second by digital data transmission nomenclature.

IBM Card-to-Card VF Method

The card-to-card transceiver developed by International Business Machines Corporation is the only "high-speed" data transmission method presently in extensive use. From a recent AIEE paper by C. R. Doty and L. A. Tate,[3] we learn that the VF channels made available in transceivers employ on-off keying, AM. The four channels provided for operation in a voiceband vehicle are located at 800, 1300, 1800 and 2300 cycles. The bit rate is 180 per second, 90 cycles. Fortuitous loss due to the unfavorable ratio between bit rate and carrier may be appreciable, particularly on the two lower frequencies.

By present-day filter and oscillator techniques, it would seem feasible to secure somewhat better spectrum economy. Analogy with other successfully operating systems would indicate that 350 or 400-cycle channel separation should be adequate. The IBM transceiver system has the definite merit of avoiding the use of too long d-c operated legs or loops by requiring carrier operation all the way on the subscriber's set.

Bell Laboratories Work

In the Bell Telephone Laboratories there was developed a system which transmits 650 bits per second. It is described in a paper by Horton and Vaughn which appeared in Volume 34 of the BELL SYSTEM TECHNICAL JOURNAL in May, 1955.[5] This system employs a carrier located at 1200 cycles and which is amplitude-modulated. The location of the carrier at 1200 cycles avoids any serious trouble from delay distortion either on the average derived voiceband or on metallic pair circuits. Within the range from 700 to 1700 cycles, which the authors mention as the required band, nonuniformity of delay is certainly at a minimum, probably not exceeding 200 microseconds.

Of considerable interest and significance in the field of high-speed data transmission is the work done by AT&T with teletypesetter signals at 600 wpm between New York and Boston. For a description of the system evolved for this purpose, we are indebted to Harold A. Rhodes whose AIEE Conference Paper No 56-397 entitled "Test of Intercity Transmission of Teletypesetter Signals at 600 Words per Minute," was presented at the AIEE Winter Meeting in New York in February 1956.[4] Mr Rhodes outlines the characteristics of the system very well in a table of design information, a part of which is reproduced here.

Specification Data on 600-Word-per-Minute Channel

Operations per Minute	3600
Characters per Second	60
Words per Minute	600
Stop Interval	1.32 Bits
Code Bits	6
Start	1 Bit
Total Bits per Character	8.5
Character Time — Milliseconds	16.23
Bits per Second — (Bauds)	510
Time per Bit — Milliseconds	1.96

The carrier, located at 1900 cycles, is amplitude-modulated. Modulation keying is direct, off-on, with no intermediate frequency. With 255-cycle modulation on a 1900-cycle carrier, keying loss would not

be excessive. The locations of the first order sidebands are 1645 and 2155. It is pointed out that the receiving filter with considerable "roll-off," made of low-Q coils, is designed to pass the band of frequencies from 1000 to 2800 cycles. The degree of roll-off compared to the extremely sharp discrimination of the "vehicle band" is shown by Figure 1. It is pointed out that the roll-off is advantageous from the standpoint of "ringing." Quite likely the advantage gained is entirely analogous to the band-shaping technique sometimes employed in facsimile transmission. This roll-off characteristic is practically unavoidable in narrower band filters used for conventional telegraphy. The "keyer" is operated by on-off signals with +120 volts for mark, and zero volts for space. Incidentally, marking signal is represented by the presence of carrier and spacing by the absence. The receiving terminal delivers +40 volts for mark and zero volts for space. Specific telegraph level is −5 dbm as compared with −21

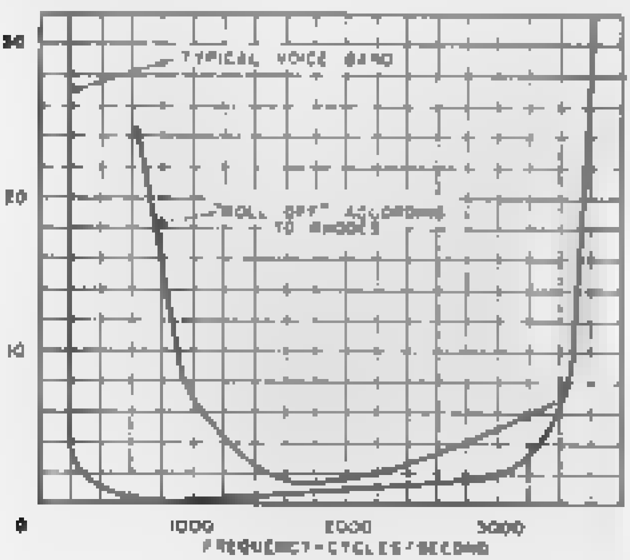

Figure 1. "Round nosed" or "roll-off" filter sometimes used for signal shaping

dbm for multichannel telegraphy at 60 wpm. The receiving amplifier detector is equipped with an automatic gain control capable of taking care of slow changes of received level of 8 db plus and minus.

The system was operated experimentally for a period of several days. Maximum distortion when worked from New York to Boston over a Type K carrier channel is reported as varying from 3 to 10 percent. On the basis of observations made during these tests, Mr Rhodes concludes that a speed of between 750 and 1000 bits per second may be realized on good telephone bands.

Lincoln Laboratories Studies

A high-speed bit transmission system devised by Lincoln Laboratories is described by Harrington, Rosen and Spaeth in the Proceedings of the Symposium on Information Networks held in New York, April 12-14, 1954.[5] This system aims to provide a 1600-bps information rate in a voiceband. The authors impose upon themselves the handicap of presuming a transmission circuit which may have a rapidly increasing attenuation characteristic above 2200 cycles. In an effort to transmit information at an 800-cycle rate on a carrier located at 2000 cycles, they encounter the necessity both for vestigial sideband modulation and for some means of mitigating excessive keying loss. This fortuitous distortion effect which results from too few carrier cycles per information bit they overcome by synchronizing the carrier frequency with the bit rate. This possible solution has been suggested by numerous earlier investigators. All have found it somewhat complicated and awkward of reduction to practice.

The method is open to the objection also that the transmission band over which such signals are passed needs to be delay-corrected with a fairly high precision. The vestigial sideband method is possibly open to some objection from the standpoint of susceptibility to noise on the vehicle band. The authors disclose that the system employs 75-percent modulation, however, whereas the usual vestigial sideband technique employs no more than 50-percent modulation. Perhaps with the synchronous carrier-bit relationship a larger modulation index is permissible. This system too includes a receiving filter with a roll-off. It is said that care must be taken to restrict the rate of attenuation outside the pass band to avoid "ringing" caused by the filter itself.

Sperry Rand Development

The Remington Rand Univac Division of Sperry Rand Corporation, formerly

Engineering Research Laboratories of St Paul, has done considerable work in this field. The system developed there under the guidance of C. W. Fritze was operated experimentally over local physical pair circuits about 30 miles long provided by the Telephone Company. This system presumes a full voiceband as the facility and locates the carrier at the top edge of that band, at about 3200 cycles. It transmits 3200 bits per second with one carrier cycle per information bit. A technical description of the system is not yet available, but presumably the modulation method requires that the carrier frequency be in synchronism and bear an accurate phase relation to the information bits transmitted.

Western Union's Proposed Method

Two principal considerations have guided our initial development work toward a system which employs only half a voiceband. The term "subband" mentioned earlier is perhaps a more apt expression to use than "half voiceband." The subband, which is very similar, incidentally, to AT&T's restricted band trunk circuit designated as "emergency channel," passes frequencies from about 200 cycles to just above 1600 cycles. As vehicle facilities for 8- and 9-channel telegraph groups, we pretty much blanket the country with a tight network of subbands.

It should perhaps be made clear that we do not use two "half bands" one from 200 to 1600 and another from 1800 to 3200 cycles. Rather, from each 3-kc voiceband, we literally derive two low-frequency bands each of which is more or less identical and in which for low-speed telegraphy we operate channels at 375, 525, and so forth, with the present top channel located at 1575. Under the new equipment designs each subband will also carry a channel at 1725, making a 10-channel group. These improved subbands have their cutoff point located just above 1760. Besides being the universal vehicle for multichannel telegraph groups, subbands are capable of carrying standard speed facsimile if a vestigial modulation system is used, and over them one may carry on a very acceptable telephone conversation.

Transmission and relative delay characteristics of the typical subband are shown by Figure 2. The relative delay curve is reasonably symmetrical about the 1150-cycle point. The intrinsic delay becomes of interest only when consideration is given to answer-back or error-correction methods. This intrinsic or absolute delay may be thought of as the fixed propagation time in the mid-band region. For any given subband circuit there are three principal contributing factors. The subband modulation equipment, sending and receiving, accounts for approximately 1000 microseconds. The voiceband carrier equipment, sending and receiving, introduces another 900 microseconds. The broad-band carrier line, including repeaters, adds 7 or 8 microseconds per mile. It should not be surprising, therefore, when we learn that the time required to get a confirmation signal back from a terminal 500 miles distant is at least 11.8 milliseconds.

The universality of the subband was an important consideration in the decision to investigate its "high-speed" potentialities. Secondly, we are drawn a bit to the conclusion that its "intermediate" high speed will in fact move data quickly enough to

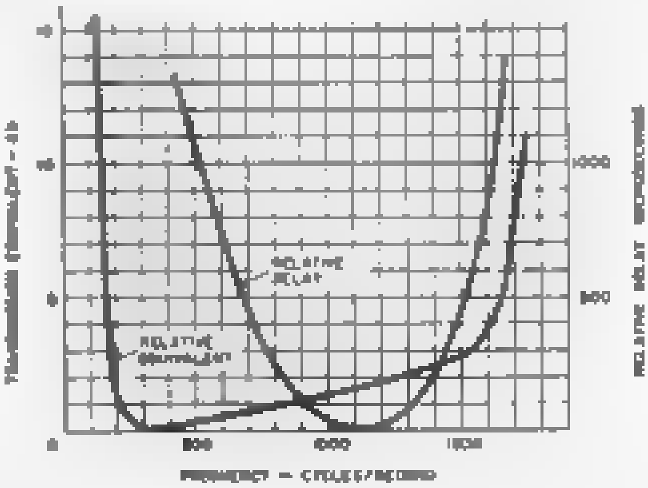

Figure 2. Transmission properties of average subband

satisfy a very substantial part of the electronic business-machine demand. There is the attractive promise that if this be so, the economics of data transmission will be more favorable and its use will more rapidly become widespread. Our program has as its first goal the determination of the conservatively high quality, error-free speed attainable in the subband.

In the selection of a modulation method and of design parameters, long-term stability of the equipment and the deficiencies of commonly-used vehicle bands were controlling. Extraneous disturbance, in important magnitude, is present at times on all communication circuits. The telephone user ordinarily is not conscious of occasional bursts of disturbance, impulse noise, equal even to signal magnitude. At least he is not annoyed until such "hits" occur so frequently as to render a telegraph channel operated under the same circumstances quite useless.

Much of this kind of noise is caused by disturbance peaks having a duration of a fraction of a millisecond. Such peaks result from any transient such as is caused by lightning in the neighborhood of the communication line, by accidental contacts with wires or cable conductors, resulting from maintenance or construction work, and from numerous other natural and man-made sources. Overloading, too, of equipment carrying not only our vehicle band but a great multiplicity of other services, produces very sharp noise peaks, as viewed in the voiceband. Negative feedback amplifiers now extensively used in carrier system repeaters produce a characteristic "hit" effect when occasionally they do overload.

These effects are infrequent from the telephone user viewpoint but may be too frequent for high-speed printing telegraphy by pulse or AM methods. Automatic as well as manual switching from one communication facility to another brings similar impulse interference of short duration. Depending upon its magnitude, noise peaks of this general type, to which a narrow-band telegraph channel would be completely oblivious, may conceivably mutilate a high-speed bit beyond recognition. For these reasons, lowest possible susceptibility to impulse noise is mandatory.

Vestigial sideband systems definitely do not possess noise suppression characteristics. A vestigial method offers the very attractive advantage, of course, that almost twice as many information bits may be transmitted through a given unit of spectrum space. Still if it is going to be twice as susceptible to disturbance peaks, it is no good except in conjunction with transmission systems which incorporate compensating redundancy.

Other carrier modulation methods considered were, of course, conventional amplitude modulation, on-off keying, and frequency modulation, frequency shift keying as it is sometimes called. The relative merits and relative disadvantages of these have been recited and reviewed by many authors.[6,7,8] The works to which we refer here are those which compare AM and FM on the basis of equal spectrum usage. The use of FM as a means of exchanging bandwidth for accuracy, as in the FM program broadcasting, is not yet seriously contemplated for domestic telegraphy or data handling.

The work recorded in the three papers referred to here agrees very well in substance. All show a substantial noise improvement factor attributable to FM. Its exact magnitude depends upon the character of the disturbance. All agree too on the advantage of FM in the face of level changes due to the vehicle carrier system. The conclusions of these papers differ only in their appraisal and judgment of probable circuit stability and noise conditions on the vehicle.

Equipment costs for frequency modulation are only just slightly more than for AM. The space, weight, complexity and maintenance factors are only very slightly different. The FM modulator is as readily susceptible to the application of transistors as is the AM.

Experimental Efforts

Some of the problems met in the choice of system parameters for maximum speed error-free transmission in a subband required experimental solution. No equipment designs had ever been undertaken prior to the initiation of Western Union's high-speed project. In fact, at the outset, little was known of the relative delay characteristics of this vehicle. All experience with lower speed designs indicated that the mid-frequency should be so located that upper and lower first order sidebands of the maximum information

rate frequency would encounter equal relative envelope delay The over-all delay characteristic, subband plus equipment, dictates a nominal carrier at about 1100 cycles. Immediately it is recognized that a considerable keying loss will attend an effort directly to modulate such a low-frequency carrier at the hoped-for information rate. Experience points up also the extreme difficulty of building a linear discriminator covering anything like an octave of frequency range. These two considerations both dictate strongly that the original modulation and the final detection be done at a "temporary" high frequency

Other solutions have been suggested for the fortuitous keying loss problem, but to date none is considered satisfactory and practical. Numerous workers on this and analogous projects have not recognized, it seems, that the high-frequency carrier "translated" downward by a linear single-sideband modulator was in fact a method of avoiding the difficulty Among the alternatives are automatic frequency control at the receiving terminal and keying synchronized with the carrier The former is difficult and complex of implementation when the keying is simple on-off AM When it is FM, the equipment complexity is prohibitive. Carrier-intelligence synchronization may sound reasonable if the keying is AM but here again FM makes this method complicated

In the system under development, the original keyed carrier can be said to be 7500 cycles. (This particular number and those used in the following discourse on the downward translation scheme are selected as convenient and approximate only) Of course, the nominal mid-frequency does not appear except instantaneously as the shift is made from 7050 cycles which represents "yes" to 7950 cycles which represents "no" (presuming a modulation rate of 900 bits)

The linear transfer modulator is driven by an 8600-cycle carrier This modulator then produces the desired set of intelligence-bearing carrier and sidebands at the subband frequency range and, of course, the unused image set of similar sidebands centered about 16,100 cycles. The subband range signals are a faithful reproduction of the original signals except that a new carrier has been substituted and the sidebands have undergone a mirror image inversion. In this new location, the "yes" bit is represented by 1550 cycles and the "no" bit by 650 cycles.

The signals, now ready to be transported to their destination by way of the subband, contain only the keying uncertainty which associates naturally with the ratio of the information frequency to the "temporary" frequency of 7500 cycles. Here we properly remind ourselves also that because of the push-pull nature of FM signaling, keying loss is only half what it is with on-off amplitude modulation and the simple half-wave detector rectifier commonly used Were this not so, we should probably have chosen a higher "temporary" frequency for the initial keying

At the receiving terminal, a transfer modulator precisely like the one in the transmitter moves the signals back to their original "temporary" carrier frequency before the information is extracted. Back at the high location "yes" is again represented by a shift below the nominal center frequency, and "no" by a shift above. The temporary high-frequency signals and the line position low-

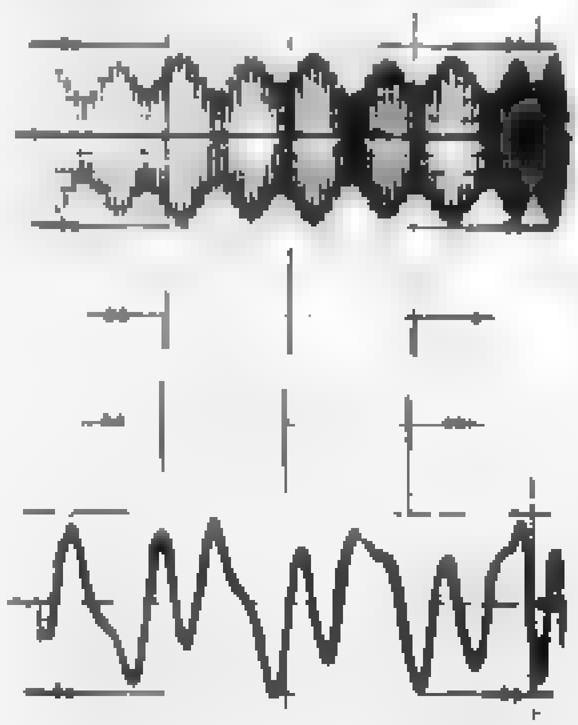

Figure 2. Frequency shifted signals as generated and as "transported"

frequency signals are shown by the oscilloscope photos of Figure 3. In the upper photo, the frequency change at high frequency, is barely discernible. The shift, completed in a fraction of the bit duration, is accompanied by a dip in amplitude. In the lower photo, a "yes" bit is represented by about two cycles of 1550 and the "no" by a half cycle of 650. In the high-frequency location, the faithful recovery of the original information wave is not difficult. A linear discriminator of the required width at 7500 cycles is entirely possible. The separation of information frequency from carrier frequency by means of filters following the detector is a simple matter. Detection at the subband location, on the other hand, would be virtually impossible on both counts.

In the absence of other requirements or standards, the carrier channel terminal has been designed to accept and deliver intelligence signals on a single current on-off basis. At the sending end, the transmitting machine is expected to open and close a "loop" circuit of about 2000 ohms impedance in which about 10 milliamperes flow. On the receiving side, the carrier terminal delivers 10 milliamperes from a 70-volt source to an equipment impedance which may range from 2000 to 4000 ohms. Moderately low impedances are maintained to avoid undue susceptibility to interference from external equipment and wiring. "Loop" control circuits are presumed to be capable of maintaining steady state direct current and to exhibit no appreciable upper frequency cutoff below approximately 1000 cycles.

Electromechanical relays, of course, are not contemplated. On the carrier side, nominal impedances are 600 ohms and levels delivered and accepted are those which are compatible with conventional carrier telegraph practices.

The criterions of telegraph transmission quality are essentially as established for lower speed services.[8] Total distortion from all causes will not be allowed to exceed 15 percent of bit length.

Bias distortion can presumably easily be held to 5 percent. Characteristic distortion resulting from nonuniform delay will very likely always be the speed-limiting factor. From the work done thus far on this method, it has been confirmed that the relative delay characteristic of the transmission circuit is of utmost importance. The db transmission equivalent of the subband definitely is not a direct criterion of the efficient operating speed. The delay curve, rather, appears to be controlling. The degree of envelope delay distortion correction practicable is perhaps the most serious question. Technically, envelope delay correction is no longer difficult due to the work of Cannon, Biggs and others.[10,11] The measuring instrument for its measurement is a tool for an engineer, to be sure, but it is accurate and dependable. The correction network is entirely practical and not too costly. Until corrected circuits are extensively used, the alternate route and circuit flexibility considerations may be controlling.

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Mr Bromholl's biography appeared in the April 1954 issue of Technical Review

ARCHIE S. HILL, Assistant to Systems Planning Engineer

Auxiliary Facsimile Developments

A major portion of the efforts of Western Union Telefax engineers during the past few years has been directed to increasing the range of adaptability of the facsimile method to existing record communications requirements. In the normal coverage of facsimile equipment and complete systems, some ingeniously contrived and desirable features of, or adjuncts to, facsimile machines may not have received the attention merited. Two interesting items are a synchronous power supply for Desk-Fax machines in d-c powered areas and an automatic stylus adjustment.

WESTERN UNION'S postwar program to improve terminal handling of telegrams called for the installation of Desk-Fax transceivers in customers' offices by the tens of thousands. Low machine cost was a first consideration. Pertinent to this discussion, some costs were avoided by (1) dependence upon commercial a-c power available throughout most cities for the necessary synchronous operation of connected machines, and (2) performing all phasing in the comparatively few central office transmitters and recorders. The ratio of central office machines to customers' machines is usually about ten to one.

Photo R-10,355

Desk-Fax transceiver atop a synchronous power supply unit

Only one line pair is used between the central office and the customer's Desk-Fax. The pair is simplexed to provide a conductor for signaling, automatic controls, and phasing on a polarized ground return basis from potentials applied at the central office. On stand-by no current flows over the line simplex and the Desk-Fax consumes no power.

When a call is initiated by either terminal, direct current flows over the line simplex. A phasing cam on the drum shaft of the Desk-Fax interrupts the direct current for a very short interval once each drum revolution. By these short open pulses the connected central office machine phases with the Desk-Fax.

Vibropack 7141-A

In a few business areas of some cities, notably Boston, Chicago and New York, only d-c power is commercially available. The Desk-Fax of a customer in such an area is powered by a vibrator-type power pack whose electromagnetically driven reed has a natural frequency slightly higher than 60 cps.

At the central office, a sample of the commercial a-c supply at a few volts is permanently applied across the line pair through a regulating network. The amplitude of the a-c sample is below the threshold of recording sensitivity at both terminals.

On stand-by, the power pack is deenergized and consumes no power. In addition to the reed vibrator it contains (1) a start

This is some of the material provided by the author for a conference paper by Warren H. Bliss, R.C.A. Laboratories, Princeton, N. J., presented at the Winter General Meeting of the American Institute of Electrical Engineers, New York, N. Y., January 1957.

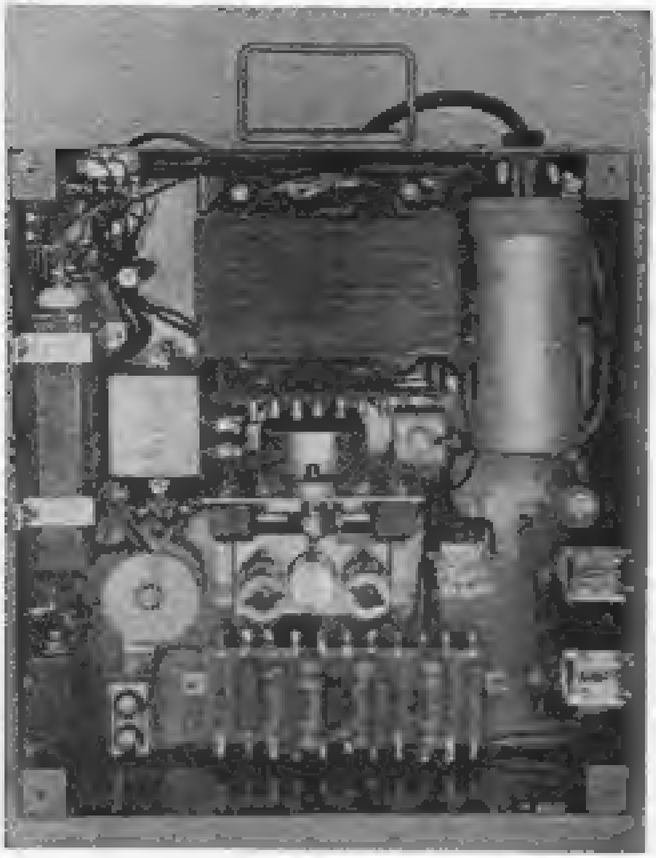


Photo R-3243

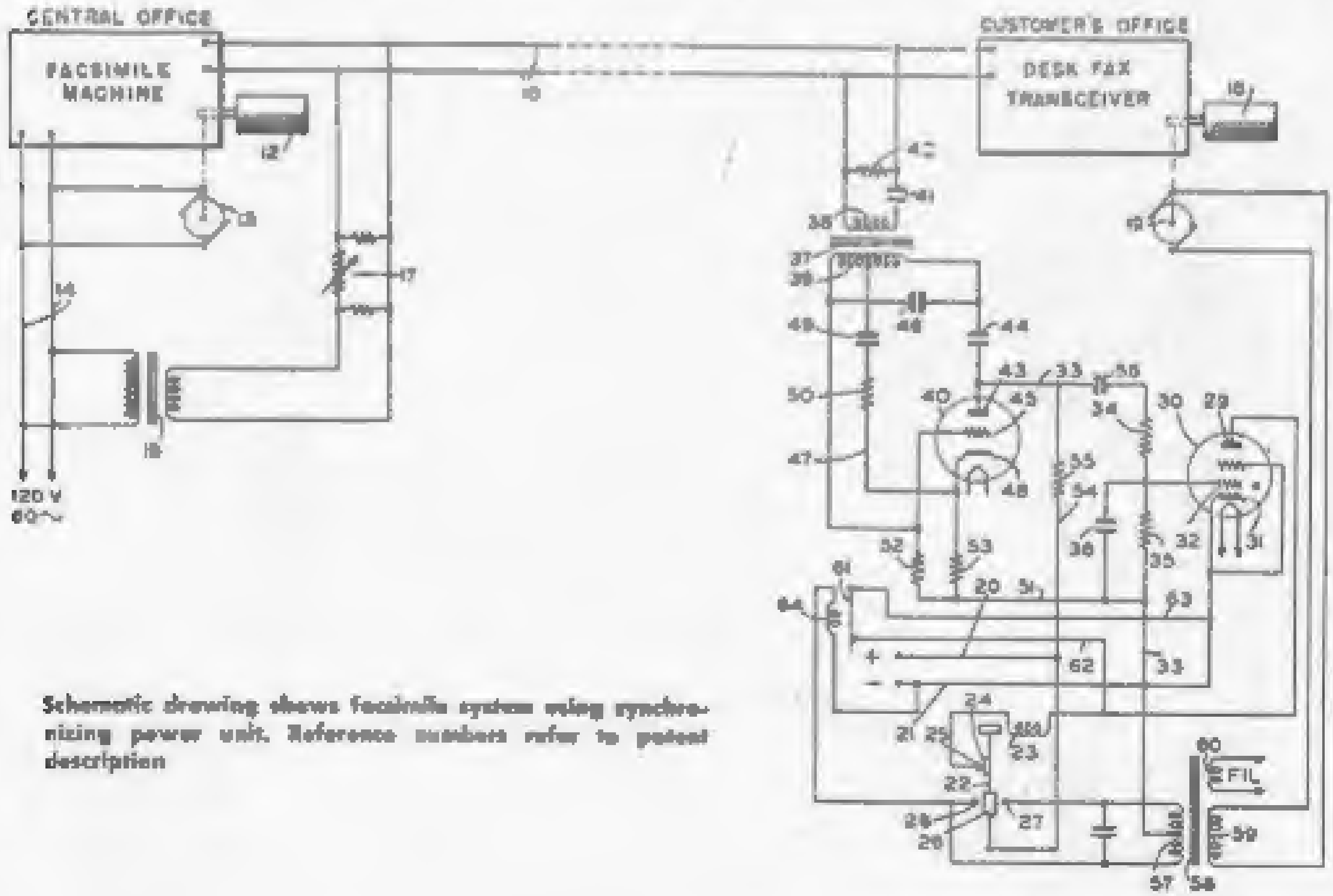
Interior of vibrapack as originally made; rebuilt for Desk-Fax

relay whose coils are in series with the line simplex, (2) a tuned 60-cycle line signal amplifier whose output is impressed upon a grid of (3) a thyratron tube, and (4) a motor-driven timing unit which operates sets of contacts by which functions of the power pack are performed in the proper sequence.

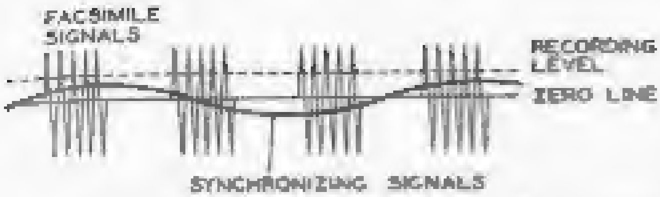
When on stand-by with the power pack deenergized, pairs of contacts keep the thyratron shorted, plate to cathode, and shunt the line simplex with an R-C network which prevents the short Desk-Fax phasing pulses from passing over the simplex line to the central office.

In Operation

When a call is initiated by either terminal, current flows in the line simplex energizing the start relay in the power pack. Contacts of the relay complete a circuit from positive direct current through the reed driving contacts and magnet coils to ground. The reed then vibrates at its natural frequency and converts d-c power to a-c power in the conventional manner. The a-c power at proper potentials is connected to (1) the Desk-Fax machine, in series with a local relay which operates to make the power pack independent of the start relay, (2) a timing unit motor, and (3) the heaters of the amplifier tube and the thyratron.



Schematic drawing shows facsimile system using synchronizing power unit. Reference numbers refer to patent description



Signal wave diagram indicates synchronizing signals do not interfere with facsimile signals

After about 12 seconds, during which time all tubes have become sufficiently heated, contacts of the timer remove the grounds from, and connect the reed vibrating magnet coil to, the plate of the thyratron. The grid of the thyratron causes it to become conductive once for each cycle of the sample of the central office a-c power. The normal contacts of the reed open the driving coil circuit once in each vibrating cycle removing positive potential from the plate of the thyratron and extinguishing it. The reed, now controlled by the firing of the thyratron, vibrates and converts the d-c input power to a-c power at a frequency exactly the same as that of central office power. Two seconds after the thyratron has taken control of the vibrator, timer contacts remove the R-C network shunt from the simplex line, permitting the Desk-Fax phasing pulses to reach the central office. Facsimile operation then proceeds normally.

At the completion of message transmission and following the normal stopping of the connected facsimile machines, the power pack continues to operate for about 1-1/2 minutes after which it is shut down by the timing unit and assumes its stand-by condition. If, during this 1-1/2-minute interval, another call is initiated in either direction, the power pack continues to operate throughout the second transmission plus the additional 1-1/2 minutes and finally assumes its stand-by condition.

This development was carried out by Charles Jelinek, Jr., and Alfred A. Steinmetz, in whose names U. S. Patent 2,737,622 has been issued.

Multistylus Point Adjustment

The multistylus belt arrangement provides a convenient method for making variable length recordings on dry electrosensitive paper from a continuous roll. Inherent with the arrangement, however, are problems not encountered with single stylus recording. The recording points of the styli must be equally spaced with high precision. This precludes the availability of any appreciable stylus flexibility to compensate for wear by abrasion and erosion.

A mechanism developed by Raleigh J. Wise and Douglas M. Zabriskie and built into Western Union's Letterfax recorder (Type 7219) automatically readjusts the lengths of styli at the end of each message, eliminating a need for frequent maintenance attention. (See lettered illustrations.)

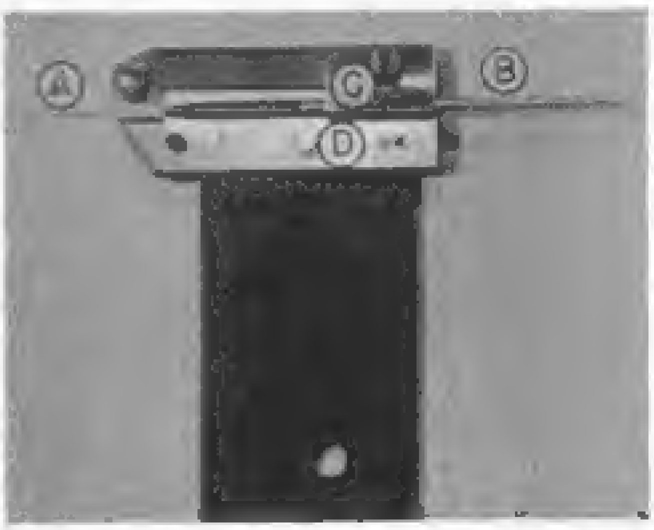


Photo M 4001

The stylus assembly and a section of the belt, showing the stylus point, pusher and retaining springs

The belt (L) mounting four stylus holders is supported between and sprocketed on a driving pulley and an idler pulley. The circumferences of the pulleys are equal to the space between styli so that the stylus on the section of belt on a pulley is always in the same radial position on the pulley.

A stylus (A) of 10-mil tungsten wire, and a stylus pusher rod (B) are held by spring (C) pressure in a guide in the stylus holder (D). The stylus projects from one side and the pusher rod projects from the other side of the holder.

On the side of the idler pulley over

which the stylus projects, and along the radial line to the stylus position on the pulley, there is an arm (E) supporting a hardened, semispherically shaped anvil (F). Flush with the other side of the idler pulley there is a one-cycle cam (G), whose action is perpendicular to the side of the pulley (H).

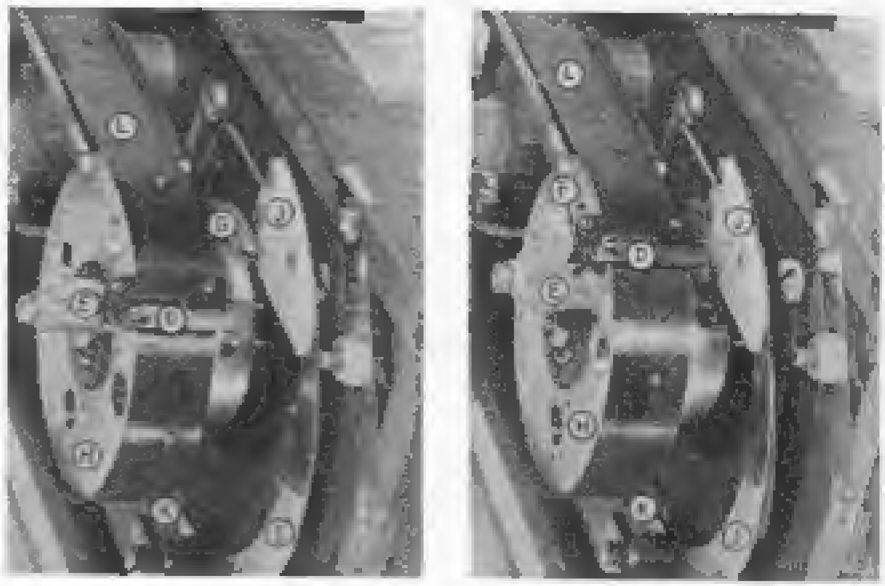


Photo R 10,820

Section of recorder showing stylus adjustment mechanism. Left — Striking arm held in inoperative position by solenoid armature (K). Right — Striking arm impacting stylus pusher

A striking arm (I) is hinged and sprung so that a nylon faced striking section (J) of it tends to bear against the activating surface of the cam or the stylus pusher.

While a message is being received, the striking arm is held away from the cam by the armature (K) of a deenergized solenoid (not shown).

When the recording of the message is completed the solenoid is energized, putting the striking arm under the control of its spring and the pulley cam. The rate of paper feed is greatly increased until a predetermined length is fed out and automatically cut off. The stylus belt continues to run during the fast feedout period preventing snagging of the paper. During the few seconds of fast paper feed, the cam causes the nylon section of the striking arm to strike each stylus pusher rod in succession during each of six or more belt revolutions causing all stylus points to be made flush with the positioning anvil. All styli are then of precisely equal length for the recording of the next message.

Mr. Hill's biography appeared in the October 1954 issue of Technical Review.